PB85-191690

# Controlling Asbestos Loss from Asbestos-Cement Pipe in Aggressive Waters

Bellevue Dept. of Public Works, WA

Prepared for

Environmental Protection Agency, Cincinnati, OH

Apr 85

U.S. Department of Commerce
National Technical Information Service
NTIS

PB85-191690

EPA/600/2-85/042
April 1985

# CONTROLLING ASBESTOS LOSS FROM ASBESTOS-CEMENT PIPE IN AGGRESSIVE WATERS

By

Carol H. Tate, Brian L. Ramaley,
John J. Vasconcelos, and Bruce M. Chow
James M. Montgomery, Consulting Engineers, Inc.
Pasadena, California 91101

Cooperative Agreement CR807789010

Project Officer

Gary S. Logsdon
Drinking Water Research Division
Water Engineering Research Laboratory
Cincinnati, Ohio 45268

This study was conducted in cooperation with the
City of Bellevue, Washington.

WATER ENGINEERING RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

**TECHNICAL REPORT DATA**
*(Please read Instructions on the reverse before completing)*

| | | |
|---|---|---|
| 1. REPORT NO.<br>EPA/600/2-85/042 | 2. | 3. RECIPIENT'S ACCESSION NO.<br>PB85 191690 /AS |
| 4. TITLE AND SUBTITLE<br>Controlling Asbestos Loss from Asbestos-Cement Pipe in Aggressive Waters | | 5. REPORT DATE<br>April 1985 |
| | | 6. PERFORMING ORGANIZATION CODE |
| 7. AUTHOR(S)<br>C.H. Tate, B.L. Ramaley, J.J. Vasconcelos, B.M. Chow | | 8. PERFORMING ORGANIZATION REPORT NO. |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS<br>Bellevue Department of Public Works<br>P.O. Box 97<br>Bellevue, Washington 98009 | | 10. PROGRAM ELEMENT NO. |
| | | 11. CONTRACT/GRANT NO.<br>CR 807789 |
| 12. SPONSORING AGENCY NAME AND ADDRESS<br>Water Engineering Research Laboratory-Cincinnati, OH<br>Office of Research and Development<br>U.S. Environmental Protection Agency<br>Cincinnati, OH 45268 | | 13. TYPE OF REPORT AND PERIOD COVERED<br>Final 12/80 - 12/84 |
| | | 14. SPONSORING AGENCY CODE<br>EPA/600/14 |

15. SUPPLEMENTARY NOTES

Project Officer: Gary S. Logsdon (513) 684-7345

16. ABSTRACT

A project was conducted to evaluate measures for controlling loss of asbestos fibers from asbestos-cement (A/C) water distribution pipe under aggressive water conditions. During Phase 1, water quality data were analyzed for the distribution system of Bellevue, Washington, which receives water from the Seattle Water Dept. The water was shown to be aggressive to A/C pipe. The pilot tests in Phase 1 evaluated eight corrosion control strategies. Zinc chloride/pH adjustment was chosen for the Phase 2 field test. Phase 1 also involved the selection of quantitative measures to determine the hardness of A/C pipe before and after exposure to aggressive water. The Shore "D" and Rockwell "L" hardness tests were found useful. In Phase 2, a test and a control loop were established in the distribution system, with samples collected before and after exposure to A/C pipe at monthly intervals for 1 year. Addition of 0.6 mg/L zinc chloride in an isolated pressure zone in Bellevue. The control was another zone. Immediately before the Phase 2 field test, the Seattle Water Department began its full-scale corrosion control program. Thus both sections received water adjusted upward in pH and alkalinity, complicating the ability to separate the effects of zinc from the effects of pH and alkalinity adjustment. Results over time from the test section with zinc chloride and the control section were similar, suggesting that alkalinity and pH increases in effect at the time of the field test may have acted to protect the pipe from deterioration.

17. KEY WORDS AND DOCUMENT ANALYSIS

| a. DESCRIPTORS | b. IDENTIFIERS/OPEN ENDED TERMS | c. COSATI Field/Group |
|---|---|---|
| | | |

| | | |
|---|---|---|
| 18. DISTRIBUTION STATEMENT<br>RELEASE TO PUBLIC | 19. SECURITY CLASS *(This Report)*<br>UNCLASSIFIED | 21. NO. OF PAGES<br>232 |
| | 20. SECURITY CLASS *(This page)*<br>UNCLASSIFIED | 22. PRICE |

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

# DISCLAIMER

The information in this document has been funded wholly or in part by the United States Environmental Protection Agency under assistance agreement number CR807789 to the City of Bellevue, Washington. It has been subject to the Agency's peer and administrative review, and it has been approved for publication as an EPA document. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

# FOREWORD

The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water systems. Under a mandate of national environmental laws, the agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. The Clean Water Act, the Safe Drinking Water Act, and the Toxics Substances Control Act are three of the major congressional laws that provide the framework for restoring and maintaining the integrity of our Nation's water, for preserving and enhancing the water we drink, and for protecting the environment from toxic substances. These laws direct the EPA to perform research to define our environmental problems, measure the impacts, and search for solutions.

The Water Engineering Research Laboratory is that component of EPA's Research and Development program concerned with preventing, treating, and managing municipal wastewater discharges; establishing practices to control and remove contaminants from drinking water to prevent its deterioration during storage and distribution; and assessing the nature and controllability of releases of toxic substances to the air, water, and land from manufacturing processes and subsequent product uses. This publication is one of the products of that research and provides a vital communication link between the researcher and the user community.

This project was undertaken to evaluate strategies for controlling deterioration of asbestos and cement pipe by aggressive water. Eight water quality modifications were tested on a pilot scale. The most successful approach involved use of a zinc salt. This technique was then evaluated in a portion of the Bellevue, Washington water distribution system.

Francis T. Mayo, Director
Water Engineering Research Laboratory

## ABSTRACT

A project was conducted to evaluate measures for controlling the loss of asbestos fibers from asbestos-cement water distribution pipe under aggressive water conditions.

Previous investigations had indicated that asbestos-cement (A/C) pipe could deteriorate when the water was low in pH, alkalinity and calcium. Initial laboratory tests suggested that the addition of zinc chloride was a promising control measure to curtail pipe deterioration and asbestos fiber loss. This control measure was then tested to evaluate control strategies in the field.

The project was divided into two phases: (1) data collection and pilot tests of alternative control strategies, and (2) field testing of the most effective control strategy.

During Phase I, water quality data were analyzed for the existing distribution system of the City of Bellevue, Washington, which receives its drinking water from the Seattle Water Department's Tolt and Cedar River systems. Samples were collected each month for 1 year from both sources before and after exposure to A/C pipe. Both sources were shown to be aggressive to A/C pipe, but the Tolt supply was more so.

Selection of control measures was complicated by the fact that the Seattle Water Department had recently completed a corrosion study and was planning to institute its own corrosion control program of pH adjustment for both the Tolt and Cedar supplies. Therefore the pilot tests assumed the proposed Seattle Corrosion Control Program as a baseline.

The pilot tests in Phase I evaluated eight alternative control strategies for curtailing pipe deterioration, including pH adjustment and addition of zinc chloride, sodium metasilicate, or ferric chloride. The zinc chloride/pH adjustment strategy performed best and was chosen for the Phase II field test.

Phase I testing also involved the selection of quantitative measures to determine the hardness of A/C pipe before and after exposure to aggressive water. The Shore "D" and Rockwell "L" hardness tests were found useful in quantifying pipe hardness.

In Phase II, a test and a control loop were established in the distribution system, with samples collected before and after exposure to A/C pipe at monthly intervals for 1 year. The test strategy was the addition of 0.6 mg/l zinc chloride at a point in Clyde Hill, an isolated pressure zone within Bellevue. The control section was in the northeastern portion of the Bellevue 520 zone. Both locations received water from the Tolt system. Immediately before the Phase II field test, the Seattle Water Department began its full-scale corrosion control program. Thus both sections received water that

had been adjusted upward in pH and alkalinity, complicating the ability to separate the effects of zinc from the effects of pH and alkalinity adjustment.

The field test in Phase II did not show conclusively whether the zinc chloride addition effectively prevented pipe deterioration and fiber loss. Results over time from the test section with zinc chloride and the control section were similar, suggesting that alkalinity and pH increases in effect at the time of the field test may have acted to protect the pipe from deterioration. Further testing of 6 to 12 months appears necessary to reach a firmer conclusion about the effect of the zinc addition.

This report was submitted in fulfillment of Cooperative Agreement No. CR 807789010 by James M. Montgomery, Consulting Engineers, Inc. under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period December 1980 to December 1984, and work was completed as of May 1984.

## CONTENTS

Foreword iii
Abstract iv
List of Tables x
List of Figures xiii
Acknowledgments xvi

1. Introduction 1

2. Conclusions 4

3. Recommendations 5

4. Background 6

    Asbestos-Cement Pipe 6
    City of Bellevue Water Supply System 6
    Raw Water Sources 7
    Distribution System 7
    Means of Assessing in the Corrosiveness of a Water 9
        Langelier Index 9
        Aggressiveness Index 10
        Saturation Index 12
        Criticisms of Corrosion Indices 12
    Potential Health Effects 13
    Previous Studies 15
    EPA-Sponsored Research 19

5. Methods 22

    Introduction 22
    Asbestos Quality Assurance 22
        Control of Contamination 23
        Analyst Performance 23
    General Inorganic Analyses 26
        Standard Curves 26
        Duplicates and Spikes 26
        Alternate Analytical Methods 29
        Check Standards 29
        Cation and Anion Balance 29
        Project Specific Quality Control 29

**Preceding page blank**

Physical Hardness 30
    Shore "D" Test 30
    Rockwell "L" Test 30
    Applying the Hardness Test to A/C Pipe Coupons 31
    Effects of Drying 31
Scanning Electron Microscope Analysis 32
    X-ray Analysis of the Pipe Surface 32
    Line Scan for Calcium Loss 32

6. Phase IA: Distribution System Characterization 35

Introduction 35
Sampling Site Selection 35
Analyses 42
    Water Quality Testing 42
    Sampling Program 43
Results and Discussion 43
    Tolt River System 43
    Cedar River System 50
    Comparison to Tolt and Cedar River Waters 57
    Hardness Testing of Pipe Samples from the Distribution System 57
Conclusions 61

7. Phase IB: Recirculation Experiments 63

Apparatus Design and Operation 63
Test Conditions and Control Strategies Examined 68
Analyses 71
    Water Quality Analyses 71
    Pipe Coupon Testing 71
    Sampling Program 72
Results and Discussion 72
    Correlation of Results 72
    Control (Tanks 1 and 2) 75
    Langelier Index Adjustment (Tanks 3 and 4) 81
    Zinc Corrosion Control Strategies (Tanks 5 and 6) 86
    Iron and Silicate Control Strategy (Tanks 7 and 8) 92
    Asbestos Analyses 92
    Physical Testing of A/C Test Coupons 99
    Weight Loss Data for A/C Test Coupons 99
    Hardness Testing of A/C Coupons 99
    Calcium Loss Via Scanning Electron Microscope Analysis 103

8 Phase II: Field Test 105

Introduction 105
Approach and Organization 105
  Site Selection 105
  Sampling Program 110
  Zinc Dose 110
  Equipment and Setup 110
  Impacts of Zinc Addition 114
  Domestic Impacts 114
  Industrial Impacts 114
Results and Discussion 115
  Startup 115
  Seattle Corrosion Control Program 116
  Asbestos Results 121
  Calcium Loss Analysis 127
  Physical Hardness Testing Results 127
  Other Water Quality Parameters 132
  Behavior of the Added Zinc 132
  Cost Comparison 148
Conclusions 155

References 158
Appendices

A. Phase IA Data
B. Phase IB Data
C. Phase II Data

# LIST OF TABLES

Table Page

1 Both Water Supplies for the City of Bellevue are Highly Aggressive

2 Effect of Corrosion Inhibitor Chemical Additions on Asbestos-Cement Pipe 2

3 Effect of Corrosion Inhibitor Chemicals on the Pickup of Asbestos Fibers 16

4 Water Quality Changes in Asbestos Cement Test Loops 18

5 Planned Water Quality After Initiation of Seattle Corrosion Control Program 20

6 Quality Control - Sample Splits with the University of Washington 21

7 Results from Internal Asbestos Sample Duplicates Performed in JMM's Laboratory During Phase I Testing 24

8 Analytical Procedures for Inorganic Water Quality Parameters 25

9 Calculated Water Quality Parameters 27

10 Initial Hardness Test Results for A/C Coupons (3/25/81) 28

11 Effect of Moisture Content on Hardness Test Experiment Results 33

12 Distribution System Characterization Phase I, Part A - Sampling Program 34

13 Water Quality of Tolt Water at Entrance to Distribution System and After Aproximately 15 Hours Detention Time in the A/C Network 44

14 Asbestos Fiber Concentration Changes Across the Tolt Distribution System 45

15 pH, Langelier Index, and Alkalinity Changes Across the Tolt Distribution System 46

16 Calcium, Silica and Hardness Concentration Changes Across the Tolt Distribution System 47

Distribution System

48

## List of Tables (Cont'd)

| Table | | Page |
|---|---|---|
| 17 | Statistical Testing (Paired-T) of Changes in Water Quality Constituents Across the Tolt Distribution System | 49 |
| 18 | Water Quality of Cedar Water at Entrance to Distribution System and After Approximately 15 Hours Detention in the A/C Network | 52 |
| 19 | Asbestos Fiber Concentration Changes Across the Cedar Distribution System | 53 |
| 20 | pH, Langelier Index, and Alkalinity Changes Across the Cedar Distribution System | 54 |
| 21 | Calcium, Silica and Hardness Concentration Changes Across the Cedar Distribution System | 55 |
| 22 | Statistical Testing (Paired-T) of Changes in Water Quality Constituents Across the Cedar Distribution System | 56 |
| 23 | Comparison of Asbestos Concentrations by Month at the Entrance to the Distribution System | 58 |
| 24 | pH, Langelier Index, and Alkalinity by Month for Tolt and Cedar Influents to the Distribution System | 59 |
| 25 | Comparison of Calcium, Silica and Hardness Concentrations by Month for Tolt and Cedar Influents to the Distribution System | 60 |
| 26 | Hardness Testing Results for Coupons Removed from the Distribution System | 62 |
| 27 | Experimental Tank Conditions | 69 |
| 28 | Recirculation Tank Experimental Program | 73 |
| 29 | Recirculation Tanks - Correlation of Results | 74 |
| 30 | Chrysotile Concentrations Over Time in the Eight Tanks | 98 |
| 31 | Amphibole Concentrations Over Time | 100 |
| 32 | Weight Changes Observed in Tank Coupons | 101 |

## List of Tables (Cont'd)

| Table | | Page |
|---|---|---|
| 33 | Hardness Test Results for Coupons Tested in Recirculation Tank, Corrosion Control Experiments | 102 |
| 34 | SEM Testing Results | 104 |
| 35 | Phase II Sampling Schedule | 111 |
| 36 | Shore "D" Hardness Test for A/C Pipe | 128 |
| 37 | Rockwell "L" Hardness Test for A/C Pipe | 129 |
| 38 | Shore "D" Hardness Test for Mortar-Lined A/C Pipe (EPA Data) | 130 |
| 39 | Rockwell "L" Hardness Test for Mortar-Lined A/C Pipe (EPA Data) | 131 |
| 40 | Water Quality Parameters | 137 |
| 41 | Statistical Comparison of Calcium Pickup Over the Control Section | 143 |
| 42 | Statistical Comparison of Silica Pickup Over the Control Section | 144 |
| 43 | Summary of a Mass Balance on Zinc in the Clyde Hill Test Area | 147 |
| 44 | Zinc Chloride Treatment Costs | 154 |
| 45 | A/C Pipe Replacement or Lining Costs | 156 |

## LIST OF FIGURES

| Figure | | Page |
|---|---|---|
| 1 | Major Water Supply Facilities in the Seattle/ Bellevue Area | 8 |
| 2 | Phase IA Sampling Points D1, D2, D3 and D4 | 37 |
| 3 | Sampling Station D1: Cedar River Water Prior to Entrance to Bellevue's A/C Pipe Network (Woodridge Pump Station) | 38 |
| 4 | Sampling Station D2: Cedar River After Exposure to the A/C Network for Approximately 15 Hours Under Average Day Conditions (Somerset 550 Pressure Zone) | 39 |
| 5 | Sampling Station D3: Tolt River Water at the Entrance to the A/C Pipe Network (NE 40th Inlet Station) | 40 |
| 6 | Sampling Station D4: Tolt River Water After Exposure to the A/C Network (NE 169th St., Seattle SDWA Sampling Station) - Site Also Used as Sample D5 for Duplicate Analyses | 41 |
| 7 | Schematic Diagram of Recirculation Test Apparatus | 64 |
| 8 | Experimental Tanks 6, 7 and 8 at Meydenbauer Hill Laboratory | 65 |
| 9 | Typical Pump and Meter Configuration - Experimental Tank Apparatus | 66 |
| 10 | Floating Covers Showing Chemical Feed Port and Sample Tap | 67 |
| 11 | pH Versus Time for Tanks 1 and 2 | 76 |
| 12 | Calcium Concentration Versus Time for Tanks 1 and 2 | 77 |
| 13 | Silica Concentration Versus Time for Tanks 1 and 2 | 78 |
| 14 | Alkalinity Versus Time for Tanks 1 and 2 | 79 |
| 15 | Hardness Versus Time for Tanks 1 and 2 | 80 |
| 16 | Calcium Concentration Versus Time for Tanks 2, 3 and 4 | 82 |
| 17 | Silica Concentration Versus Time for Tanks 2, 3 and 4 | 83 |
| 18 | Alkalinity Versus Time for Tanks 2, 3 and 4 | 84 |

## List of Figures (Cont'd)

| Figure | | Page |
|---|---|---|
| 19 | Hardness Versus Time for Tanks 2, 3 and 4 | 85 |
| 20 | Calcium Concentration Versus Time for Tanks 2, 5 and 6 | 87 |
| 21 | Silica Concentration Versus Time for Tanks 2, 5 and 6 | 88 |
| 22 | Alkalinity Versus Time for Tanks 2, 5 and 6 | 89 |
| 23 | Hardness Versus Time for Tanks 2, 5 and 6 | 90 |
| 24 | Zinc Concentration Versus Time for Tanks 2, 5 and 6 | 91 |
| 25 | Calcium Concentration Versus Time for Tanks 2, 7 and 8 | 93 |
| 26 | Silica Concentration Versus Time for Tanks 2, 7 and 8 | 94 |
| 27 | Alkalinity Versus Time for Tanks 2, 7 and 8 | 95 |
| 28 | Hardness Versus Time for Tanks 2, 7 and 8 | 96 |
| 29 | Iron Concentration Versus Time for Tanks 2, 7 and 8 | 97 |
| 30 | The Bellevue Area | 107 |
| 31 | Clyde Hill 465 Zone Pipe Network | 108 |
| 32 | Sampling Station CH1: The Inlet to the Clyde Hill System | 109 |
| 33 | The Zinc Chloride Chemical Metering Pump | 112 |
| 34 | The Zinc Chloride Injection Point on the Clyde Hill Water Main | 113 |
| 35 | The Bellevue Asbestos Control Field Test and the Seattle Corrosion Control Program | 117 |
| 36 | The pH Change at D3 and D4 Before and After the Start of the Corrosion Control Program | 118 |
| 37 | The Alkalinity Change at D3 and D4 Before and After the Start of the Seattle Corrosion Control Program | 119 |
| 38 | The Langelier Index Change at D3 and D4 Before and After the Start of the Seattle Corrosion Control Program | 120 |
| 39 | Chrysotile at the Control Area | 122 |
| 40 | Chrysotile at the Test Area | 123 |
| 41 | Joint Behavior of the Test Area (CH1-CH2) and Control Area (D3-D4) | 124 |

## List of Figures (Cont'd)

| Figure | | Page |
|---|---|---|
| 42 | Cumulative Probability Analysis for the Test Area | 125 |
| 43 | Check on Asbestos Precision Using Data from CH1 and CH1A | 126 |
| 44 | pH Behavior at the Inlets to the Test Area (CH1) and the Control Area (D3) | 133 |
| 45 | Alkalinity Behavior at the Test Area (CH1) and the Control Area (D3) | 134 |
| 46 | Temperature Behavior at the Inlets to the Test Area (CH1) and the Control Area (D3) | 135 |
| 47 | TDS Behavior at the Inlets to the Test Area (CH1) and the Control (D3) | 136 |
| 48 | Zinc Concentration Near the Injection Point (CH1A) and at the End Point (CH2) | 145 |
| 49 | Mass Balance: Accounting for Zinc | 146 |
| 50 | Average Zinc Concentrations at the Test Area | 149 |
| 51 | X-ray Spectra of A/C Pipe at CH1A | 150 |
| 52 | X-ray Spectra of A/C Pipe at CH2 | 151 |
| 53 | X-ray Spectra of Unused A/C Pipe | 152 |
| 54 | X-ray Spectrum of A/C Pipe at D3 | 153 |

## ACKNOWLEDGMENTS

James M. Montgomery, Consulting Engineers, Inc., expresses its gratitude to the many individuals who helped make this project possible:

**City of Bellevue**

Larry Southwick, Manager, Water and Sewer Utility
Walter E. Davis, Jr., Former Manager
Wes Jorgenson
Pam Bissonnette
Howard Marcum
Mike Brownlee
Joy Wherley
Susan Cezar
Lorrie Murray
David Renstrom

**Environmental Protection Agency**

Dr. Gary S. Logsdon, Project Officer
James Millette
Michael Schock
Roy R. Jones
Ed Frindt

**University of Washington**

Edwin S. Boatman

**James M. Montgomery, Consulting Engineers, Inc.**

Bruce M. Chow
John Vasconcelos
Brian Ramaley
Carol Tate
Judith Doocy
Charles Dougherty
Jeanne-Marie Hand
Dave Bliss
John Lang
Andrew Eaton
Joan Oppenheimer
Carol J. Belt
Dan Jones
Jack Bencomo

# SECTION 1

# INTRODUCTION

This report concludes an investigation of the corrosion of asbestos-cement A/C pipe corrosion and its control in the water distribution system of the City of Bellevue, Washington. The identification of airborne asbestos as a carcinogen has aroused concern that even though A/C pipe appears to be less subject to corrosion than most metal pipes, corrosion could result in the release of potentially harmful asbestiform fibers into drinking water.

The widespread use of A/C pipe for water distribution has developed largely since 1940, the approximate time at which the City of Bellevue, Washington, began to develop from a small community to its present size.

The distribution system of the City of Bellevue is primarily composed of A/C pipe: Approximately 483 kilometers (300 miles) of A/C pipe make up some 90 percent of the City's system. In addition, the water transported by this distribution system (Tolt and Cedar River Water) is highly corrosive when characterized by such indices as Langelier Index and the Aggressiveness Index. A negative Langelier Index or an Aggressiveness Index below 12 signifies an aggressive water. As Table 1 indicates, the Tolt River has an Aggressiveness Index of 7.2 and is an extremely aggressive water.

The Cedar River, which normally supplies a smaller portion of Bellevue's distribution system than does the Tolt, is slightly less aggressive, but it may also be characterized as a highly aggressive water with an Aggressiveness Index of less than 10. Frequently during summer months, the City of Seattle must reduce its supply from the Cedar River system. For this reason, it is sometimes necessary for the more aggressive Tolt water to be supplied to all of the water distribution system.

The constant presence of highly aggressive water in a distribution system composed almost entirely of A/C pipe raises serious concern about pipe corrosion and the possible presence of elevated asbestos fiber levels in Bellevue's drinking water.

Given the susceptibility of the A/C pipe to corrosion and the potentially harmful health effects of ingested asbestos fibers, this study was formulated and performed to determine and assess the water quality changes that occur in Bellevue's distribution system; to ascertain whether asbestos fibers are being released from A/C pipe to drinking water; to examine at the pilot-scale the efficacy of various control strategies for mitigating corrosion of A/C pipe; and, finally, to evaluate one of these control strategies in a field test.

## TABLE 1

## AGGRESSIVENESS OF WATER SUPPLIES FOR THE CITY OF BELLEVUE

| Water Source | Average* Aggressiveness Index | Average* Langelier Index |
|---|---|---|
| Tolt River | 7.2 | -5.0 |
| Cedar River | 9.9 | -2.1 |

* Average of 9 samples collected at entrance to Bellevue's distribution system in 1981-1982.

The work in this study was conducted in two phases. Phase I characterizes the distribution system and evaluates corrosion control strategies through recirculation experiments. Phase II field tests a corrosion control strategy.

# SECTION 2

# CONCLUSIONS

The following conclusions apply to the project as a whole. They are based on the results and conclusions of the individual sections presented in this report.

1. Monitoring results strongly indicated that portions of the asbestos-cement pipe matrix were dissolving into the supply water. This situation was indicated by increases in water concentrations of components most associated with pipe dissolution: calcium, silica, chrysotile fibers, pH, and alkalinity. Before alkalinity and pH control was initiated, water from the Tolt supply was more aggressive toward the pipe matrix than the Cedar supply.

2. Although a natural background of chrysotile fibers exists in the water supply, monitoring results and pilot studies indicated that the asbestos-cement pipes do release these fibers into the water.

3. Hardness tests such as the Shore "D" and the Rockwell "L" tests are useful for determining the condition of asbestos-cement pipe. However, the natural variability in the samples and method results suggest that periods greater than 1 year are required for determining statistically whether any changes in hardnesss have occurred. The Shore "D" test can be conducted in the field with a small, hand-held durometer.

4. Older asbestos-cement pipes removed from the Bellevue network show softening as measured by the Shore "D" and Rockwell "L" tests. These tests might be used to determine a priority system for a planned replacement program.

5. Although zinc chloride was effective in controlling asbestos-cement pipe corrosion in the pilot test, no determination could be made about its effectiveness under field test conditions. This uncertainty may have been the result of compounding effects of the alkalinity and pH control recently initiated by the Seattle Water Department for the source water supply.

6. The alkalinity and pH control may be protecting the asbestos-cement pipe or at least slowing down the deterioration. Evidence of this effect appears in the chrysotile data for the field test. Both the control area and the test area (with zinc chloride added) behaved the same, showing a decrease in fiber pickup over the course of the field test.

7. Evidence from the field test suggests that the zinc accumulated in the test area as both particulate and deposited zinc.

## SECTION 3

## RECOMMENDATIONS

The following recommendations are based on the results and conclusions of this report.

1. Zinc chloride should be further tested in an area that has not undergone alkalinity and pH control. Evidence of zinc deposition on the inner pipe walls suggests that zinc chloride is potentially effective in protecting asbestos-cement pipe. Also, tests at Greenwood, South Carolina, have been successful using another form of zinc (zinc orthophosphate), which further indicates the potential effectiveness of zinc treatment. Zinc chloride is less expensive than zinc orthophosphate, however, and it does not promote algae growth.

2. The control area used in the field test should be monitored further to determine whether the alkalinity and pH control was effective in protecting the A/C pipe. Constituents which should be monitored include chrysotile fibers, calcium, silica, pH, alkalinity, TDS, and temperature.

3. Hardness testing using the Shore "D" and Rockwell "L" hardness tests should be standardized for general use by the water industry.

# SECTION 4

# BACKGROUND

## ASBESTOS-CEMENT PIPE

Asbestos is a general group of fibrous silicate minerals composed largely of impure magnesium silicate arranged in a chain-type fashion. A/C pipe was first developed in Italy in the early 1900's. Its development grew out of a desire to produce a strong, corrosion-resistant piping material for use in areas where corrosion of metallic materials had proved to be a problem. In A/C pipe, asbestos is mixed with cement in concentrations of 10 to 25 percent so that the fibers will bind and reinforce the cement matrix of the pipe wall. Piping composed of this asbestos-cement material is common in water distribution systems throughout the United States. Olson (1974) estimated that more than 322,000 kilometers (200,000) of A/C pipe are in service in the United States. A/C pipes have been listed by manufacturers as having a number of advantages. Among them are the following:

- A high resistance to corrosion, both internal and external
- Sufficient strength to withstand internal loads imposed by water hammer and shock earth loads imposed by earthquakes
- Benefits to water quality since A/C pipe does not rust, cause water discoloration, or contain jute and other types of joints that serve as focal points for bacterial growth
- Lightness in weight, (A/C pipe is one-fifth the weight of cast iron or ductile iron) that results in lower installation costs, and
- A permanently smooth interior wall that results in low pumping costs.

## CITY OF BELLEVUE WATER SUPPLY SYSTEM

The City of Bellevue is a suburb on the east side of the City of Seattle, Washington, with a population of approximately 100,000. It is bounded on the west by Lake Washington and on the east by Lake Sammamish. Bellevue receives its drinking water from Seattle's East Side Supply Line (ESSL), which consists of the Tolt supply from the north and the Cedar supply from the south. The ESSL is the primary water supply line providing water to the suburbs on the east side of Seattle. Other communities that receive water from the pipeline include Mercer Island, Redmond, and Kirkland. Bellevue and these other communities purchase drinking water from the City of Seattle

(Seattle Water Department) through wholesale agreements. Figure 1 shows the general layout of major water supply facilities in the Seattle area.

## RAW WATER SOURCES

The East side Supply delivers water from two upstream sources tapped by the City of Seattle. Water from the south fork of the Tolt River is delivered through the northern reach of the East Side Supply Line, and water from the Cedar River is delivered from the south. Both the Cedar and Tolt Rivers drain the west slope of the Cascade Mountain Range and the eastern portion of King County. The flow in both rivers consists largely of snow melt from these rugged mountains and is remarkably low in mineral content.

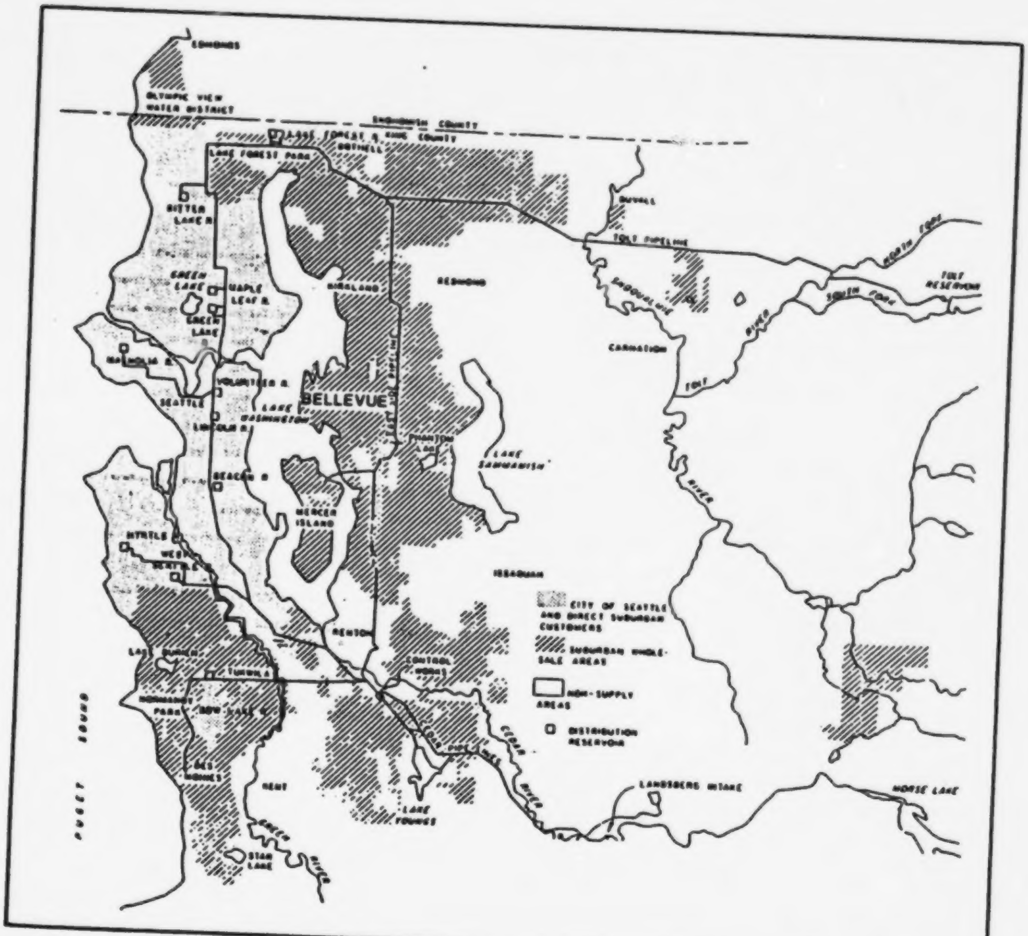
The water quality of both sources is typically excellent. Water from the Tolt River is impounded in the Tolt Reservoir on the south fork of the Tolt River while water of the Cedar River is impounded in a series of lakes and reservoirs. The water from these reservoirs is low in turbidity and comes from watersheds which are not open to the general public other than for logging. Thus, treatment by the City of Seattle has traditionally consisted of chlorination and flouridation, but no filtration. As shall be discussed later, the City of Seattle is currently treating, through chemical addition, to achieve some measure of corrosion control.

There are numerous asbestos bearing mineral deposits in the watersheds of both sources; thus, naturally occurring asbestos fibers have appeared in both water supplies. During Phase I of this study, median asbestos fiber counts were 1.46 million fibers per liter in the Tolt River and 0.66 million fibers per liter in the Cedar River at the entrance to Bellevue's distribvution system. Until recently, it was believed that asbestos fibers were not present in raw water from the Cedar River. This study, as well as previous studies conducted by the City of Seattle (Kennedy Engineers, 1976), indicate that asbestos fibers are present in the raw Cedar River water. However, the median fiber levels present in Cedar River water are approximately 50 percent of those figures for the Tolt River.

It is likely that the City of Bellevue will continue to utilize water from the Cedar and Tolt Rivers in their system, although they are studying the possibility of drawing water from the Snoqualmie River (JMM, 1978). Although this additional source for a direct supply to the City of Bellevue may be tapped at some point in the future, it is not likely that this will be realized in the next 10 to 15 years. Current analysis of this source of supply is in the preliminary stages, prior to development of such a water supply system, it would be necessary to design and construct a number of facilities. At present it is estimated that, should this option be pursued, supply facilities from the Snoqualmie River would go on-line in approximately 1995.

## DISTRIBUTION SYSTEM

Bellevue receives water from Seattle's East Side Supply Line at several metered inlet stations. Normally, the bulk of the water in Bellevue's system is supplied from the Tolt. During summer months, however, the demand increases and the Seattle Water Department cannot serve the northern extremes of its Cedar system, such as Bellevue, from


EDMONDS
OLYMPIC VIEW WATER DISTRICT
SNOHOMISH COUNTY
LAKE FOREST & KING COUNTY
BOTHELL
LAKE FOREST PARK
DUVALL
TOLT PIPELINE
NORTH FORK
TOLT RESERVOIR
SOUTH FORK
BITTER LAKE R.
GREEN LAKE
MAPLE LEAF R.
GREEN LAKE
KIRKLAND
REDMOND
SNOQUALMIE
CARNATION
TOLT
RIVER
MAGNOLIA R.
VOLUNTEER R.
SEATTLE
BELLEVUE
LAKE WASHINGTON
LINCOLN R.
PHANTOM LAKE
LAKE SAMMAMISH
RIVER
BEACON R
MERCER ISLAND
MYRTLE
WEST SEATTLE
ISSAQUAH
CITY OF SEATTLE AND DIRECT SUBURBAN CUSTOMERS
SUBURBAN WHOLE-SALE AREAS
NON-SUPPLY AREAS
DISTRIBUTION RESERVOIR
RENTON
LAKE BURIEN
TUKWILA
CONTROL WORKS
NORMANDY PARK
BOW LAKE R.
CEDAR RIVER
DES MOINES
KENT
LANDSBERG INTAKE
MORSE LAKE
LAKE YOUNGS
GREEN RIVER
STAR LAKE
PUGET SOUND

**MAJOR WATER SUPPLY FACILITIES IN THE SEATTLE/BELLEVUE AREA**
**(KENNEDY ENGINEERS)**

FIGURE 1

the Cedar River supply. Thus, the City of Bellevue may receive Tolt water exclusively at all its metered inlet stations. This condition may also reduce supply from the Tolt system for various reasons, including elevated turbidity levels. Under these conditions, Cedar River water may be received throughout most, if not all, of Bellevue's distribution system. The City of Bellevue is particularly susceptible to this type of source shifting because it is geographically located at the mid-point of the East Side Supply Line. Thus, as supply from one source or the other increases or decreases, the boundary between areas served by either Cedar or Tolt River water shifts. Since Bellevue is at the mid-point, it is the first community to feel such shifts.

The topography and configuration of the Bellevue water distribution system are rather complex. Service connections from the distribution system vary from 15 to 1500 feet above sea level in elevation, and thus it is necessary to divide the distribution system into numerous pressure zones. Each of these pressure zones typically involves inlet and outlet stations, relating pumping stations, storage tanks and pressure relief stations. In addition, pressure zones typically have multiple sources of supply (i.e., looped distribution system) to allow for more flexibility and dependability. Over 400 miles of pipeline are in place in the Bellevue distribution system; approximately 80 percent is A/C pipe. The remainder is ductile iron and reinforced concreete pipe.

In the last several years the City of Bellevue has discontinued the use of A/C pipe for new installations in the distribution system after it was learned that the A/C pipe was degrading and corroding within the system, requiring added maintenance to repair breaks. At present, the City utilizes cement mortar-lined, ductile iron pipe for new installations.

## MEANS OF ASSESSING THE CORROSIVENESS OF A WATER

Two common means of assessing the corrosiveness of a water with regard to A/C pipes are through the use of Langelier Index (LI) and the Aggresiveness Index (AI).

### Langelier Index

The Langelier Index was developed in 1936 (Langelier) and can be defined as follows:

$$LI = pH - pH_s$$

where:

$pH_s$ = saturation pH, the pH at which a given water is in equilibrium with solid calcium carbonate and

pH = actual or measured pH of the water.

$pH_s$ is typically calculated from the following equation which applies between pH 7.0 and pH 9.5:

$$pH_s = p(Ca^{2+}) + p(HCO_3^-) + (pK2_{2'} - pk_s')$$

where:

$pK_{2'}$ = negative logarithm of second dissociation constant for carbonic acid ($H_2CO_3$).

$K_{2'} = (H+) (CO_3^{-2})/(HCO_3-)$

$pK_s$ = negative logarithm of the solubility product of calcium carbonate (CaCO3).

$K_s' = (Ca^{2+}) (CO_3^{2-})$

$p(Ca^{2+})$ = negative logarithm of the calcium concentration and

$p(HCO_3^-)$ = negative logarithm of the assumed alkalinity (equivalents, titrable base).

A more rigorous equation applies for pH value below 7.0 and above 9.5. Corrections for temperature and ionic strength are made for each calculation.

The primary utility of the Langelier Index is that it enables one to determine whether calcium carbonate will precipitate, remain in equilibrium with, or dissolve, solid calcium carbonate within the system. A Langelier Index greater than zero implies that the water is supersaturated with respect to calcium carbonate and will tend to precipitate a protective scale of calcium carbonate onto the pipe wall. If the Langelier Index equals zero, the system is in equilibrium and no precipitation or dissolution of calcium carbonate should occur. If the Langelier Index is less than zero, the water is understaurated with respect to solid calcium carbonate. Thus it will tend to dissolve any protective calcium carbonate scale on the pipe wall and leave the pipe exposed to the corrosive qualities of the water.

It is important to note that the Langlier Index is not a direct measure of the corrosiveness of a water with respect to metallic pipe or A/C pipe. It merely describes the tendency of a water to dissolve or precipitate calcium carbonate scale which may in turn provide a protective coating. Calcium carbonate, as such, is present in A/C pipe in very small proportions; predominant phases of the A/C pipe cement matrix have been reported as tricalcium silicate, dicalcium silicate and tricalcium aluminate (Schock and Buelow, 1981). Thus, it is obvious that the L.I. is not necessarily a good indicator of a water's tendency to dissolve or soften A/C pipe. However, if a water is oversturated with respect to calcium carbonate, the Langelier Index is useful in predicting the formation of a protective scale.

## Aggressiveness Index

The A/C pipe industry developed the Aggressiveness Index as a quantitative guide for the selection of asbestos-cement as an appropriate pipe material based on concerns of structural integrity. Recently this index has also been used to determine whether water quality degradation would occur from A/C pipe dissolution. The Aggressiveness Index is defined as follows:

$$AI = pH + \log (AH)$$

where:

A = total alkalinity, mg/L as calcium carbonate, and
H = calcium hardness, mg/L as calcium carbonate

The Aggressiveness Index has some shortcomings in that it does not incorporate corrections for temperature and ionic strength. However, at a selected temperature (14°C) and ionic strength (0.01), the Aggressiveness Index can be calculated by AI = LI + 12.0. Moderately aggressive (AI between 10 and 12) to highly aggressive (AI less than 10.0) water supplies are classified as potentially corrosive to A/C pipe. In a recent study, Millette et al. (1979) determined, through sampling representative utilities throughout the United States, that 52 percent of U.S. water suppliers distribute moderately aggressive water, and 16.5 percent distribute highly aggressive water. Hence, 68.5 percent of U.S. water systems carry water capable of corroding A/C pipe as determined by characterization through the AI.

Several corrosion mechanisms are active in degradation of pipes. Electro-chemical corrosion contributes much to the degradation of metallic pipes. The metals in the pipe have a high affinity for electron donation and so produce electrochemical cells acting as anodes and donating electrons to basic constituents in the water. Hence the pipe deteriorates. Electrochemical corrosion is not an issue with regard to A/C pipe since the cement matrix (an involved combination of more than 100 compounds and phases) does not act as an effective anode for electron donation.

Thus, one assumes the cause source of A/C pipe deterioration is dissolution. Water low in calcium content, and hence aggressive, dissolves the calcium constituents in the cement portion of the pipe, which may subsequently release asbestos fibers. The fibers could be released individually or in bundles, unencapsulated by the cement matrix. Hallenbeck et al. (1979) theorized that once these fibers are released into water, they can be further broken down so that asbestos fiber counts from breakdown products are even higher. Thus, if A/C pipe is used in the transport of moderately aggressive or highly aggressive waters, there is a potential for consumers to be exposed to significant concentrations of asbestos in some drinking water supplies.

According to the National Academy of Sciences (1981),

"The use of the Aggressiveness Index represents an advance over the original preconception that A/C pipe is not subject to the effects of water quality. As recently as slightly more than a decade ago, Bean (1970) stated that A/C pipe does not require lining, even with soft water, which could be classified as aggressive water. Since that time, both manufacturers and pipe producers have acknowledged that it is not judicious to use A/C pipe with aggressive water. Thus, the Aggressiveness Index has been a means for alerting suppliers and users that A/C pipe cannot be used under all situations and that it is not resistant to corrosion in all cases. It is also simpler to calculate than the Langlier Index."

## Saturation Index

Possible calcium compound dissolution reactions for A/C pipe wall include the following:

$$Ca(OH_2)(s) \longleftrightarrow Ca^{2+} + 2OH^-$$

$$Ca_3SiO_5H(s) + 5H_2O \longleftrightarrow 3Ca^{+2} + H_4SiO_4^o + 6OH^-$$

$$Ca_2SiO_4(s) + 4H_2O \longleftrightarrow 2Ca^{+2} + H_4SiO_4^o + 4OH^-$$

$$Ca_3Al_2O_6(s) + 6H_2O \longleftrightarrow 3Ca^{+2} + 2Al^{+3} + 12OH^-$$

where (s) indicates the solid phase.

These reactions would increase the pH, alkalinity, and calcium of water in contact with the pipe. These increases would also result in an increase of the Langelier or Aggressiveness Index. An additional index has been used to determine thermodynamic equilibrium and is called the Saturation Index (SI) (Schock and Buelow, 1981). It is defined as the logarithm of the ratio of the ion activity product (IAP) to the solubility product constant ($K_{so}$). For example, the equilibrium reaction for hydroxyapatite is

$$Ca_5(PO_4)_3\ OH\ (s) \longleftrightarrow 5Ca^{2+} + 3PO_4^{3-} + OH^-$$

Assuming the activity coefficient is equal to unity, the Saturation Index (SI) can then be calculated by

$$SI = \log\ (Ca^{+2})^5\ (PO_4^{3-})^3\ (OH^-)/K_{so}$$

If the solid and solution are in equilibrium, then $SI = O$. If the solution is supersaturated, $SI > O$, and if it is understaurated, $SI < O$.

## Criticisms of Corrosion Indices

Each of the various indices used for predicting the relative corrosiveness of a water with respect to A/C pipe is subject to criticism. The Langelier Index and the Aggressiveness Index are both indicators of the tendency of a water to dissolve or precipitate calcium carbonate. Thus, their application or usefulness in determining if A/C pipe will be attacked by a given water is limited. In addition, the intrinsic assumptions utilized in deriving the AI further hinder its usefulness. More detailed "critiques" of the AI and the LI have been presented in the literature (Schock and Buelow, 1981; Schock, 1984). In recent years, both of these indicators have come under increasing strutiny in regard to their application to A/C pipe.

Schock and Buelow (1981) have proposed the use of Saturation Index information for assessing the suitability of A/C pipe use with potentially corrosive waters, and to predict the efficacy of certain corrosion control strategies. This approach has been utilized in selecting the experimental corrosion control strategies tested in the study reported herein. However, even Saturation Index methods are somewhat limited at present and do not offer fail-safe predictions. Many of the pipe wall constituents are present in varying amounts in the pipe, do not have well defined dissolution reactions and solubility constants are unknown in some cases. In addition, a number of solids may precipitate to form a protective scale and it is difficult to include all possible candidate compounds in analyses. It is also necesary, except for very simple aquatic systems, to use large, complex computer programs to model the aqueous chemical equilibria in a given source water. For this study, the program called REDEQL.EPAK (Schock and Buelow, 1981) was used to predict chemical doses and pH conditions necessary to achieve pipe protection through scale precipitation. The type of approach needs further refinement and data acquisition should be directed at correlating modeling predictions to actual system reaction and further identification and refinement of the notable chemical reactions involved.

## POTENTIAL HEALTH EFFECTS

Asbestos is a known carcinogen when inhaled, but data concerning its effects when ingested are inconclusive. Most research to date has been inconclusive or produced contradictory results. Harold Olson (1974) showed the death rate from gastrointestinal cancer to have declined in the U.S. while the use of A/C pipe has greatly increased. Kay (1974) revealed no evidence for gastrointestinal cancer occurrence from the intake of Ontario water containing asbestiform fibers in concentrations of approximately 25,000 to 2.5 million fibers/L (MFL) and mass concentrations of 0.25 and 2.5 mg/L. The city of Duluth, Minnesota, found asbestiform concentrations in its drinking water to be nearly forty times that of the Ontario supplies and still there was no evidence of cancer occurrences stemming from the drinking of tap water containing asbestos fibers. In a recent study at Seattle's Fred Hutchinson Cancer Research Center, nearly 45,000 cancer cases in the Seattle metropolitan area were studied and no link to asbestos in drinking was was found. Dr. Lincoln Pollisar of the Center stated in a recent interview that, "While we do not see the effects of asbestos in our data, this does not mean there is no risk. However, if there is any risk, it is very small" (Kirkland Courier Review, July 29, 1982).

Almost all epidemiologic studies conducted to date have examined the effects of naturally occurring asbestos fibers in drinking water; since fibers released from A/C pipe tend to be longer, chrysotile fibers, the results of these studies may not extrapolate well to A/C pipe systems.

Nonetheless, as pointed out in a study by McCabe and Millette (1979), higher than expected rates of peritoneal mesothelioma, gastric, kidney and colon cancer were experienced by workers occupationally exposed to airborne asbestos. This suggests that ingested asbetos may in fact be a problem since much inhaled asbestos is cleared from the respiratory tract and swallowed. An experiment with rats showed one-third of the inhaled asbestos fibers settled on the surface of the respiratory tract and were transported to the gastrointenstinal tract within an hour. In addition, a study in the San Francisco Bay Area (Kanarek et al., 1980) did show a statistically signficant correlation between fiber levels in drinking water and the incidence of various forms of cancer.

Another study by Wright (1978) of the Research Foundation Committee concluded gastrointestinal cancer to be dose-related and not affected by the type of asbestos absorbed. Cancers generally occurred at exposure levels many times greater than are present in drinking water, but there are other parameters, such as the effect of fiber length (fibers released by A/C pipe being longer than those found in the environment) on cancer incidence, which remained unexplored at present.

In its continuing work with the National Academy of Sciences (NAS), the EPA requested an independent investigation of the potential health effects of asbestos in drinking water. In a draft version of "Drinking Water and Health, Volume 5", not yet published, the NAS reviewed the recent reports from the toxicological and epidemiological studies on asbestos in drinking water. The NAS concluded that the animal feeding studies were negative (showed no relationship between asbestos ingestion and cancer) and that the evidence from human epidemiological studies was weak. In particular, two studies in the Seattle are have shown negative results for asbestos. The University of Washington, Fred Hutchinson Institute epidemiological study of asbestos in drinking water and cancer incidence in the Seattle and Everett areas concluded there was little evidence that asbestos in drinking water altered cancer risk. A recent University of Washington study, again comparing Everett and Seattle, suggested no relationship between asbestos fibers in drinking water and the number of fibers in voided urine. Only the study of the San Francisco Bay area indicated a link between asbestos and cancer, and that was only found in the City of San Francisco itself (a phenomenon attributed to some unidentified "San Francisco factor").

However, the next step by the NAS called into question whether the animal toxicological studies and epidemiological studies as conducted would be capable of detecting a link between asbestos and cancer at the levels of asbestos found in various drinking water supplies. Using data from human inhalation exposure plus risk extrapolation models used previously by EPA, the NAS made several assumptions to estimate risk levels to humans drinking asbestos fibers in water. These calculations showed incremental lifetime cancer risks as follows:

| | |
|---|---|
| Men: | 110,000 fibers per liter (0.11 MFL) may lead to one additional gastrointestinal tract cancer in 100,000 men over 70 year lifetime. |
| Women: | 1,700,000 fibers per liter may lead to one additional gastrointestinal tract cancer in 100,000 women over 70 year lifetime. |

The NAS compared the results of their calculations to the human and animal data on ingested asbestos and concluded that their calculations were consistent with the studies within their statistical limits. In other words, the fact that no effects were observed in the studies does not demonstrate that asbestos is not linked to health effects; it does reflect the fact that low level risks could not be detected because of the design of these studies.

An additional source of information on the health effects of ingested asbestos derives from an EPA workshop on this topic. Papers from the workshop are contained in the November, 1983 issue of Environmental Health Perspectives.

It should also be explained that the current study does not attempt to address the issue of health significance of ingested asbestos fibers, either those naturally occurring or those which may be released from A/C pipe during the transmission of drinking water. This study merely examines the release of fibers and other materials from the pipe wall and addresses various means of mitigating that release.

## PREVIOUS STUDIES

In 1976, the Seattle Water Department conducted an internal corrosion study (Kennedy Engineers, 1976), to evaluate the nature and degree of corrosion in the Department's water distribution system. The findings presented in this report showed water with a number of characteristics believed to be conducive to corrosion including a low pH, a high dissolved oxygen content, free carbon dioxide, a high halogen to bicarbonate ratio and, of primary importance to this study, an aggressiveness to solid calcium carbonate stemming from an undersaturation with respect to calcium carbonate (negative LI) within the water supply.

The Seattle Water Department found Tolt and Cedar River waters to be very aggressive to its own metal pipes. Although Seattle has very little A/C pipe in its own distribution system, it did notice in some of its tests that, when Tolt and Cedar River water was passed through asbestos cement pipe, changes in water quality did occur. Testing facilities for asbestos cement pipe were added to the pilot units utilized to study Tolt and Cedar water. The purpose of these A/C pipe units was to determine the degree of corrosiveness of Tolt and Cedar water with respect to A/C pipe and to evaluate means of corrosion prevention.

The Seattle Water Department employed the following four measures to evaluate internal A/C pipe corrosion:

1. Weight loss.
2. Electron microscopy-spectrum analysis.
3. Asbestos fiber pickup.
4. Water quality analyses.

Each A/C pipe test section was Class 150 A/C water pipe, 3 meters (10 feet) in length, 10 centimeters (4 inches) in diameter, with a volume of 27 liters (6.5 gallons). The flow rate through the pipe was 5.7 liters per minutes (1.5 gallons per minute) and the pilot plant test unit utilized was a once-through system as opposed to re-circulation experiments utilized in the work reported herein.

The City of Seattle study also employed A/C coupons approximately 3.8 by 2.5 centimeters (1-1/2 by 1 inches) to determine A/C corrosion. The coupons were weighed and inserted into the pipe for test runs. The coupons were weighed and examined by microscopy three times during this study: at 44, 129, and 218 days exposure. Corrosion rates were calculated from coupon weight differential. Table 2 shows the results of the weight loss study. Initially, there was a high corrosion rate or weight loss rate probably due to the release of loosely bound cement. After release of this loosely bound binding material to aggressive waters, the corrosion rate declined to a lower, uniform rate.

The Seattle study examined corrosion control strategies utilizing various chemical feed systems: lime, soda, ash, zinc orthophosphate, and sodium silicate. However, since the Seattle Water Department has only a few miles of A/C pipe in its system and is not primarily interested in providing for mitigation of corrosion of A/C pipe, the A/C pipe studies were somewhat limited in scope.

In general, the results of the Seattle study indicate that, based upon weight loss, water quality and asbestos fiber pickup, both Tolt and Cedar water are very aggressive with

## TABLE 2

## EFFECT OF CORROSION INHIBITOR CHEMICAL ADDITIONS* ON ASBESTOS-CEMENT PIPE

| | | Percentage Weightloss[1] | | | |
|---|---|---|---|---|---|
| | | Unit #1 | Unit #2 | Unit #3 | Unit #4 |
| Source | Exposure Period Days | Control | Lime + Soda Ash pH 9.0+ | Lime + Zinc Orthophosphate pH 8.0+ | Sodium Silicate pH 7.5 - 8.0 |
| Cedar | 43 | 1.29 | 0.52 | 0.95 | 0.99 |
| | 128 | 1.41 | 1.15 | 1.15 | 1.15 |
| | 219 | 2.85 | 1.74 | 1.74 | 2.40 |
| Tolt | 44 | 1.54 | 0.62 | 0.92 | 1.28 |
| | 129 | 2.06 | 1.42 | 0.77 | 1.68 |
| | 218 | 4.36 | 3.05 | 1.96 | 3.49 |

[1] Percent weightloss $= \frac{\text{Initial Wt - Final Wt}}{\text{Initial Wt}} \times 100$

* (Kennedy Engineers, 1978)

regard to A/C pipe. This study also concluded that none of the inhibitor strategies investigated provided significant corrosion inhibition for A/C pipe. However, the study concluded that for Cedar water, lime and soda ash provided the best observed inhibition of corrosion of A/C pipe and for the Tolt River, lime and zinc orthophosphate appeared to give the best protection. Of the corrosion control strategies investigated, sodium silicate appeared to provide the least amount of protection.

The Seattle study employed scanning electron microscopy and spectral analysis to examine coupon surfaces both before and after exposure to Tolt and Cedar River water. Due to the generally rough, pitted, and variable surfaces of the A/C coupons, the results of the tests proved inconclusive.

Water samples from both the Tolt and Cedar River were analyzed during the Seattle study for asbestos fiber content. These analyses demonstrated that asbestos fibers were present in both water sources prior to exposure to A/C pipe. In addition, the study attempted to perform paired analyses to compare asbestos fiber release before and after exposure to A/C pipe. Water samples were allowed to stand for 23 hours exposed to A/C pipe coupons and then drawn off and analyzed for asbestos fiber content. The results, shown in Table 3, also indicated that none of the inhibitor strategies investigated inhibited the release of asbestos fibers into Cedar River water. Both with and without fiber bundles counted, the number of asbestos fibers present in the Cedar and Tolt water increased over that of the control situation in which there was exposure to A/C pipe, but no corrosion inhibitor was used. However, the report stated that these results were anomalous, and possibly related to the method of sampling. Therefore, no definite conclusion concerning inhibitor effectiveness was made on these results.

Sampling and analysis for water quality changes were conducted as part of the same experiment mentioned in the previous paragraph. Each sample was analyzed for pH, alkalinity and calcium content. Results from these analyses are shown in Table 4. These results indicate that Cedar River water is aggressive upon initial contact with A/C pipe and becomes neutral or over-saturated with respect to calcium carbonate after 23 hours. This would imply that no further significant change in water quality would be likely to occur after 23 hours of exposure. In addition, the analyses showed that no corrosion control strategy had a significant effect on calcium, alkalinity or pH increase in the testing program.

In the Tolt River samples, however, the lime and zinc orthophosphate corrosion stategy appeared to reduce calcium pickup significantly as opposed to both the control system and other corrosion control strategies tested. However, similar to the results for the Cedar System, the Tolt analyses showed that with 23 hours contact time, Tolt was near or approaching saturation with respect to calcium carbonate.

As a result of this study, the Seattle Water Department has implemented their own corrosion control program primarily aimed at preventing degradation of galvanized iron and copper home plumbing systems. The Tolt River supply is treated by lime and soda ash addition in order to achieve a more favorable (less negative) Langelier Index and a more stable water. Approximately 10 mg/L of soda ash ($Na2CO3$) is added while lime ($CaO$) addition is varied in order to maintain a pH of approximately 8.2 at the

## TABLE 3

## EFFECT OF ADDITION OF CORROSION INHIBITOR* CHEMICALS ON THE PICKUP OF ASBESTOS FIBERS

| Source | Sample | Treatment | Chrysotile Asbestos Fibers<br>$10^6$ fibers/liter |
|---|---|---|---|
| Cedar River | Source | Control - No exposure to asbestos cement pipe. | 2.02 |
| | Unit #1 A.C. | Control - No inhibitor chemical addition. | 4.64<br>6.44 (bundles included) |
| | Unit #2 A.C. | Lime + Soda Ash<br>pH 9.0± | 5.46<br>5.90 (bundles included) |
| | Unit #3 A.C. | Lime + Zinc Orthophosphate<br>pH 8.0±, Zn 0.30 mg/l | 5.62<br>6.79 (bundles included) |
| | Unit #4 A.C. | Sodium Silicate<br>pH 7.5-8.0, $SiO_2$ 10-12 mg/l | 6.30<br>6.66 (bundles included) |
| Tolt River | Source | Control - No exposure to asbestos cement pipe. | 1.35 |
| | Unit #1 | Control - No inhibitor chemical additional. | 3.60 |
| | Unit #2 | Lime + Soda Ash<br>pH 9.0± | 6.56<br>9.50 (bundles included) |
| | Unit #3 | Lime + Zinc Orthophosphate<br>pH 8.0±, Zn 0.30 mg/l | 2.21<br>3.65 (bundles included) |
| | Unit #4 | Sodium Silicate<br>pH 7.5-8.0 | 5.25<br>10.64 (bundles included) |

* (Kennedy Engineers, 1978)

treatment works. Cedar River water receives lime addition in order to maintain a similar pH at the Cedar River treatment works. The chemical feed systems started in July, 1982 for the Tolt supply and in January, 1983 for the Cedar supply. The Seattle Water Department gradually increased chemical dosages until the desired pH. alkalinity and calcium levels were reached in April 1983 for the Tolt and in May, 1983 for the Cedar supply. The target levels shown in Table 5 are currently maintained in the system. Sodium levels in the Tolt are also controlled as a result of soda ash addition. A more detailed discussion of the Seattle Corrosion Control Program and its effect on Bellevue water is given in Section 8.

As a result of the corrosion control program which the City of Seattle has implemented, the water which the City of Bellevue receives is less aggressive with respect to asbestos cement pipe than water received in the past. However, since the Seattle Corrosion Control Program was not aimed specifically at A/C pipe, this water is still somewhat corrosive to A/C pipe.

One important consideration of the newly instituted Seattle corrosion control program is the fact that throughout the course of the study reported herein, it has been necessary to view each of the findings in light of the changes that Seattle's corrosion program entailed both for water quality and pipe degradation.

## EPA SPONSORED RESEARCH

Kanarek et al. (1981) showed that water passing through an A/C pipe system contained a larger proportion of long fibers than water prior to entrance to the system. Hence, A/C fibers released from pipe are generally longer than those naturally present. Also, this information tended to discount the theory that higher fiber counts after exposure toA/C pipe were due to the breakup of fibers already present in the sate from natural means. A more recent study at Greenwood, South Carolina funded by EPA, (Grubb, 1981), reported that zinc orthophosphate provided a protective inner coating on A/C pipe when zinc concentrations in excess of 0.2 mg/L were maintained. further EPA studies (e.g., Schock and Buelow, 1981, Buelow et al., 1980, etc.) also reported zinc coatings as possibly preventing pipe deterioration even for water showing an aggressiveness index indicating moderate to highly aggressive water. The protective action of zinc appears to be pH dependent with high pH's providing more effective protection, implying tht the protective mechanism in more related to zinc compounds that the form of zinc added. One study (EPA, 1984) in Weston, Wisconsin found zinc chloride to be ineffective based on pipe hardness tests, but attributed the lack of success to the presence of polyphosphates used to sequester iron and manganese.

The addition of small amounts of other metal salts such as those of iron and manganese may also contribute to the formation of a protective scale. A rust-like coating was observed in one water system which exhibited surporisingly low fiber counts despite an aggressiveness index of 6.0 to 7.5 (Buelow, et al., 1980). The iron content in the water ws between 0.1 and 0.15 mg/L. In a pilot study Schock and Buelow (1981) credited iron at 0.1 mg/L with binding asbestos fibers to the pipe surface despite the fact that the surface was softened due to leaching. Therefore, the addition of iron may be able to protect A/C ppe. Schock and Buelow (1981) also mention finding one water supply where manganese may have prevented fiber release, but did not discuss this finding in detail. However, with any metal salt addition, potential effects on industrial users must be considered prior to implementation.

## TABLE 4

## WATER QUALITY CHANGES IN ASBESTOS CEMENT TEST LOOPS*

| Water Source | Corrosion Control Strategy | Date | Time | pH Units | Alkalinity as $CaCO_3$ mg/l | Calcium (Ca) mg/l | pHs | Langelier(1) Index |
|---|---|---|---|---|---|---|---|---|
| Cedar | Control | 7/21/77 | 1300 | 7.1 | 26.0 | 8.3 | 9.20 | -2.1 |
| | | 7/21/77 | 1530 | 7.3 | 33.0 | 8.8 | 9.05 | -1.75 |
| | | 7/22/77 | 1215 | 8.8 | 42.0 | 12.0 | 8.80 | 0 |
| | Lime + Soda Ash | 7/21/77 | 1240 | 8.8 | 39.0 | 10.8 | 8.90 | -0.1 |
| | | 7/21/77 | 1515 | 8.6 | 52.0 | 10.0 | 8.80 | -0.2 |
| | | 7/22/77 | 1200 | 9.7 | 56.0 | 13.9 | 8.60 | +1.1 |
| | Lime + Zinc Orthophosphate | 7/21/77 | 1225 | 7.8 | 33.0 | 10.0 | 8.0 | -1.2 |
| | | 7/21/77 | 1455 | 7.9 | 33.5 | 10.4 | 8.95 | -1.05 |
| | | 7/22/77 | 1135 | 9.0 | 43.0 | 13.2 | 8.75 | +0.25 |
| | Sodium Silicate | 7/21/77 | 1150 | 8.2 | 35.0 | 9.2 | 9.00 | -0.8 |
| | | 7/21/77 | 1440 | 8.3 | 39.0 | 9.4 | 8.95 | -0.65 |
| | | 7/22/77 | 1115 | 9.2 | 47.0 | 12.2 | 8.75 | +0.45 |
| Tolt | Control | 7/19/77 | 1305 | 5.70 | 1.5 | 2.4 | 10.95 | -5.25 |
| | | 7/19/77 | 1525 | 6.95 | 4.0 | 2.9 | 10.45 | -3.50 |
| | | 7/20/77 | 1130 | 8.10 | 7.5 | 7.3 | 9.75 | -1.65 |
| | Lime + Soda Ash | 7/19/77 | 1245 | 8.80 | 17.0 | 5.8 | 9.50 | -0.70 |
| | | 7/19/77 | 1515 | 9.25 | 18.5 | 6.6 | 9.40 | -0.15 |
| | | 7/20/77 | 1130 | 9.70 | 25.0 | 9.0 | 9.15 | +0.55 |
| | Lime + Zinc Orthophosphate | 7/19/77 | 1315 | 6.9 | 11.0 | 6.1 | 9.70 | -2.80 |
| | | 7/19/77 | 1505 | 7.4 | 12.0 | 6.2 | 9.65 | -2.25 |
| | | 7/20/77 | 1145 | 9.0 | 15.0 | 6.9 | 9.50 | -0.50 |
| | Sodium Silicate | 7/19/77 | 1230 | 7.1 | 10.0 | 2.5 | 10.10 | -3.0 |
| | | 7/19/77 | 1450 | 8.5 | 18.0 | 3.0 | 9.80 | -1.30 |

(1) Langelier Index = pH - pHs

* (Kennedy Engineers, 1978)

## TABLE 5

## PLANNED WATER QUALITY AFTER INITIATION OF SEATTLE CORROSION CONTROL PROGRAM*

| | Sodium mg/l | Calcium mg/l | Alkalinity mg/l as $CaCO_3$ | pH |
|---|---|---|---|---|
| TOLT RIVER SOURCE | | | | |
| Present Average | 1 | 3 | 4 | 6.0 |
| Planned Average | 5 | 4.3 | 14-17(1) | 7.5-8-3(1) |
| CEDAR RIVER SOURCE | | | | |
| Present Average | 2 | 6 | 18 | 7.1 |
| Planned Average | 2 | 7.4 | 18-25(1) | 7.5-8.3(1) |

(1) Since alkalinity and pH may change during water storage and distribution, only ranges can be predicted.

* Source: Seattle Water Department

# SECTION 5

# METHODS

## INTRODUCTION

This section summarizes the analytical procedures and sampling procedures used throughout the course of the study. For the routine water quality analyses such as asbestos and mineral analyses, standard EPA methods were used. However, for the less conventional tests such as the physical hardness tests used on the asbestos-cement pipe, some development was necessary.

## ASBESTOS QUALITY ASSURANCE

Asbestos analysis was made by the method described in the publication entitled "Interim Method for Determining Asbestos in Water" (Anderson and Long, 1980), which can also distinguish between chrysotile and amphibole asbestos forms. The method consists of counting asbestos fibers under a transmission electron microscope (Zeiss Model) EM-10. A known volume of water sample is filtered through a 0.1 micrometer Nuclepore filter to trap asbestos fibers, after which the filter is carbon coated. A small portion of this filter is removed and placed on an electron microscope grid after which the filter material is gently dissolved in chloroform. The material remaining on the grid is examined using the electron microscope at 20,000 magnification. The asbestos fibers are identified by their morphology and electron diffraction pattersm. Their length and width are also measured. The total area examined under the electron microscope is determined and the number of asbestos fibers in this area counted. The concentration in MFL (million fibers per liter) is calculated from the number of fibers counted, the amount of water filtered, and the ratio of the total filter area to be analyzed filter area. The detection limits are variable and depend on the amount of total particulate matter in the sample as well as the contamination level in the laboratorey environment. Under favorable circumstances, detection limits of 0.01 MFL can be obtained.

Samples were taken in clean, one liter polyethylene bottles. Except for two locations, the sample sites were set up for continuous flow to assure representative samples. The exceptions were two sites at the inlet to the Clyde Hill system in Phase II of this study. In those instances, the port was opened and allowed to run before smaploing. The sample bottles are filled to about 1/4 full and rinsed with the sample wter. This rinsing step was repeated before taking the sample. Finally the bottle was filled allowing 2-inches of air space in the bottle for shaking. No preservatives were used.

There are two major concerns in quality assurance for asbestos analyses: the control of possible sample contamination during processing in the laboratory and the experience of the analyst who performs the identification and counting of the fibers.

## Control of Contamination

Avoiding contamination of the sample by airborne or other sources of asbestos is a critical aspect of this analysis. The preparation of the sample is, therefore, performed in a clean room, "HEPA" filtered, under a laminar flow hood. A "tacky mat" placed at the entrance of the room traps any gross contamination carried on footwear. In addition, as part of the daily routine, the dilution water (prefiltered thorugh a 0.1 micron Nuclepore filter) is analyzed as a control with the samples filtered the same day. If contamination occurs, indicated by the presence of asbestos fibers in the control, the working area is thoroughly cleaned; only negative results in dilution water allow further processing of the samples.

## Analyst Performance

Each of the analysts has been thoroughly trained by an experienced analyst and has satisfactorily performed the counting of blind samples provided by the EPA and the State Health Department of California. With regard to inter-laboratory comparisons, most projects include split sample analysis with other laboratories; in the framework of the current project, samples were divided at regular intervals between the JMM laboratory and the University of Washington.

The results of quality control sample splits with the University of Washington are shown in Table 6. As can be seen from these data, values for chrysotile fiber counts recorded by the JMM laboratory, were with only a single exception, consistently below those reported by the University of Washington.

Sample filter grids for two samples collected on July 8, 1981, were exchanged between JMM's laboratory and Dr. Boatman's laboratory at the University of Washington. As can be seen from the data in Table 6, the University of Washington counts were somewhat higher for the grids exchanged. Thus, it is felt that some of the differences in the numbers reported by the two laboratories may be due to consistent differences in the analytical approach of the analysts at the two laboratories.

One encouraging factor is the fact that the differences between the two laboratories appear to be consistent. Thus, while the fiber levels reported herein may be lower than the University of Washington levels, if all samples had been analyzed at the University of Washington, the relative numbers and observed increases and decreases in fiber counts should have been consistent regardless of where analyses were performed.

Results of sample splits with other laboratories through past EPA and State of California projects have been consistently encouraging, and the data reported herein are regarded as the best available under current technology.

Duplicate samples were obtained from sampling station D-4 (to be described in Section 6) during the first six months of Phase IA testing. The results of these duplicate sample

## TABLE 6

## QUALITY CONTROL - SAMPLE SPLITS WITH THE UNIVERSITY OF WASHINGTON

| Sample Description | Chrysotile Count (MFL) | | Amphibole Count (MFL) | |
|---|---|---|---|---|
| | JMM | U. of W. | JMM | U. of W. |
| D1 - 5/6/81 | 0.66 | 2.7 | ND | ND |
| D2 - 5/6/81 | 1.97 | 4.0 | ND | ND |
| D3 - 5/6/81 | 1.57 | 10.2 | ND | ND |
| D3 - 7/8/81 | 0.66 | 2.76 | ND | ND |
| D4 - 7/8/81 | 1.97 | 14.8 | ND | ND |
| D2 - 12/2/81 | 3.29 | 9.2 | ND | 0.30(NSS) |
| D4 - 3/3/82 | 4.63 | 3.17 | ND | 0.81 |

NOTE: Filter grids were exchanged with Dr. Boatman's lab at the University of Washington. The chrysotile counts for these identical samples are shown below.

| Sample | JMM Count (MFL) | U. of W. Count |
|---|---|---|
| D3 - 7/8/81 | 0.66 | 0.8 |
| D4 - 7/8/81 | 1.97 | 6.0 |

ND denotes "None Detected"

# TABLE 7

# RESULTS FOR INTERNAL ASBESTOS SAMPLE DUPLICATES PERFORMED IN JMM'S LABORATORY DURING PHASE I TESTING

| Sampling Date | Sample 1 - D4 | | Duplicate Sample 2 - D5 | |
|---|---|---|---|---|
| | Chrysotile Fiber Count (MFS) | Amphibole Fiber Count (MFL) | Chrysotile Fiber Count (MFL) | Amphibole Fiber Count (MFL) |
| 4/2/81 | 9.44 | 0.39 | 9.45 | 0.13 |
| 5/6/81 | 3.72 | ND* | 8.66 | 0.79 |
| 6/3/81 | 7.09 | ND | 4.20 | ND |
| 7/8/81 | 1.97 | ND | 4.72 | 0.26 |
| 8/5/81 | 7.0 | ND | 3.15 | ND |
| 9/2/81 | 22.11 | ND | 19.95 | ND |

* None Detected

Note: All samples drawn from SDWA Sampling Station on NE 169th St. (see Figure 3-4).

analyses are shown in Table 7. The data in this table indicate that asbestos measurements made in the JMM laboratory are reproducible and compare favorably to other data reported in the literature.

## GENERAL INORGANIC ANALYSES

All water quality analyses performed by the JMM laboratory were conducted according to the EPA procedures designated in Table 8; calculated parameters are shown in Table 9. On-site analyses included pH by a standard pH probe, dissolved oxygen using a Yellow Springs International Model 51B Dissolved Oxygen Meter, chlorine residual using a Hach test kit (DPD colorimetric method), and temperature using a standard mercury thermometer. Some of the initial zinc analyses in the field test were sent to an outside laboratory in the Bellevue area. The results from the zinc analyses were used to calibrate the chemical feed system. However, the routine zinc monitoring samples were analyzed in the JMM laboratory.

Mineral samples were taken in 500 mL polyethylene bottles. These bottles were rinsed twice with the water used for sampling and then filled to overflowing. The bottles were capped and checked to see that no air bubble was included when the cap was tightened; no preservatives were used for these samples. The metal samples, including zinc, were taken in 125 mL polyethylene bottles. Samples were preserved with 0.25 mL of 8 N nitric acid which was placed in the bottles before sampling. Soluble zinc samples were filtered thorugh a 0.45-micron filter using a 22 mL glass syringe before being placed in the bottles.

There are several different components of quality assurance for the general mineral and metals analyses performed for this project. These include the use of standard curves for all analyses to ensure proper instrument operation, use of duplicates and spikes to monitor precision and accuracy, and the use of check standards to monitor instrument and analytical performance. Each of these procedures is described below.

### Standard Curves

As part of the normal standardizaton procedure for minerals and metals other than asbestos, a standard curve, derived from at least three points, is generated before any samples are analyzed. If a standard curve is not linear or is significantly different from previous standard curves run on the same instrument (e.g., for atomic absorption if the sensitivity is different from past runs), the instrument performance is checked before any further analyses are run to ensure that the instrument has the proper performance. Once the sensitivity has been verified, samples are run. Additional blanks and standards are analyzed after approximately every 10 samples. This allows the analyst to monitor and correct for instrument drift.

### Duplicates and Spikes

For inorganic analyses performed routinely, duplicates and spikes are used with a frequency no less than 10 percent of the time to mark the precision and accuracy. Duplicates are added to sample runs after every 10 samples and the range between

## TABLE 8

## ANALYTICAL PROCEDURES FOR INORGANIC WATER QUALITY PARAMETERS

| Parameter | Procedure |
|---|---|
| Alkalinity | EPA 310.1 |
| pH | EPA 150.1 |
| Total Dissolved Solids | EPA 160.1 |
| Specific Conductance | EPA 120.1 |
| Ammonia | EPA 350.1 |
| Fluoride | EPA 340.2 or 340.3 |
| Silica | EPA 370.1 |
| Metals | |
| Zinc | EPA 289.1 |
| Iron | EPA 236.1 |
| Major Ions | |
| Bicarbonate | EPA 310.1 |
| Calcium | EPA 215.1 |
| Chloride | EPA 325.0 or IC |
| Magnesium | EPA 242.1 |
| Manganese | EPA 243.1 |
| Nitrate | EPA 353.2 or IC |
| Potassium | EPA 258.1 |
| Sodium | EPA 273.1 |
| Sulfate | EPA 375.2 or IC |

## TABLE 9

## CALCULATED WATER QUALITY PARAMETERS

| Calculated Parameter | Parameters Used |
|---|---|
| Bicarbonate | pH, alkalinity |
| Hardness | Ca, Mg |
| Langelier Index | Ca, alkalinity, TDS, temperature |

duplicates compared to control chart parameters which have been developed though on-going analyses. The control charts establish the expected range between duplicates. When duplicate results fall outside the control limits, all samples between these duplicates are redone after the cause for unacceptable reproducibility is established.

Samples are spiked with an approximate frequency of 10 percent in order to verify that there are no matrix interferences causing poor recovery and inaccurate results. Recovery from major elements must be between 90 and 110 percent and for minor elements they must be between 80 and 120 percent. If recovery falls outside these limits, the analyses are rerun. If the low recoveries are due to matrix effects on samples, all samples with a similar matrix are analyzed using standard additions rather than being directly compared to standard curves.

## Alternate Analytical Methods

As an additional cross-check, approximately five percent of the analyzed samples were cross-checked by an alternative analytical method wherever such a method is available. As an example, colorimetric analyses for anions such as nitrates, sulfates, flourides and chlorides are also checked by ion chromatography, and colorimetric analyses which can also be performed by titration (e.g., alkalinity) are cross-checked by both methods.

## Check Standards

As part of its overall assurance, the JMM laboratory routinely participates in the analyses of blind check standards submitted to the lab. These include EPA performance samples (WS series), other check standards provided the lab is certified (30 at present), and blind samples submitted by in-house quality assurance personnel. Results for these standards are reviewed and any potential problems are immediately addressed to take appropriate corrective action.

## Cation and Anion Balance

On any general mineral type analysis (major cations and anions), data are also verified on the basis of ion balance, which compares the cation and anion sum to ensure that the difference falls within expected ranges. For drinking waters, the normal criteria is with 0.15 Meq/L or plus or minus two percent, whichever is greater. In addition, calculated conductivity is checked against measured conductivity, and TDS by addition is compared to measured TDS to determine which constituents are most likely to be in error. This provides an additional level of quality assurance which supplements the use of standards, blanks, and replicates to ensure proper data verification.

## Project Specific Quality Control

All of the procedures discussed above are part of the routine quality control program in the JMM laboratory. In addition in this project, the analysts were aware of the expected range of a given parameter, values were checked against the expected concentration for each analyses. If a discrepancy was larger than would be expected based on previously observed variations, the data were re-checked before being reported. This practice is particularly useful for the general mineral analyses where knowledge of prior values may give the analyst an additional idea as to where the problem may lie if the analysis did not balance ionically.

## PHYSICAL HARDNESS

For this study, it was desirable to have some means of assessing the effects of the Tolt and Cedar River waters on the interior surfaces of A/C pipe. Optimally, this test should be reproducible and produce a minimal amount of spread in the results for replicate samples. The USEPA has previously employed a subjective method (Buelow et al., 1980) for determining whether interior surfaces of A/C pipe coupons have been softened. This procedure consisted of scratching the coupon with a thumbnail to determine hardness, much as a minerologist would do in identifying a mineral. One goal of this project was to find a more objective procedure for testing A/C pipe hardness. Two possible candidates for hardness tests were the Shore "D" and Rockwell "L", both of which are used routinely in the materials science field.

The concept of hardness is the resistance to indentation by a hard ball or cone under a given static load. In theory, since the release of asbestos fibers and the general deterioration of A/C pipe in water is related to the deterioration of the cement matrix (Millett, 1983), the hardness or sponginess of the remaining A/C pipe material should be a measure of its condition.

Hardness tests were conducted by Northwest Labortories of Seattle. In Phase II, duplicate hardness tests were also conducted by the USEPA.

### Shore "D" Test

The Shore "D" analysis is a member of a class of durometer tests normally used for hard rubber or plastics. A load is applied to a calibrated spring which forces a sharp point into the material. The Shore "D" test has the sharpest point and the heaviest load of the durometer tests. The Shore "D" hardness range from 100 which indicates 0 indention to 0 which indicates a 0.25 cm (0.1-inch) indention. The minimum coupon thickness should be 0.64 cm (1/4-inch) and the minimum separation between indention marks should be at least 1.3 cm (1/2-inch). For this study, the coupons were about 1.9 cm (3/4-inch) thick and 2.5-5 cm (1 to 2-inches) wide. For each coupon, three separate readings were taken and then averaged to give a single reading for the coupon.

### Rockwell "L" Test

The Rockwell "L" tests consists of a penetrator which is usually a steel ball or a diamond cone with a rounded point. A minor load of about 10 kilograms is used to set an initial indention after which an additional major load of 60 or 100 kilograms is applied to make the final indention. For the Rockwell "L" test a 60 kilogram major load is used. The steel penetrator ball diameters range from 0.16 cm to 1.27 cm (1/16 to 1/2-inches) in diameter. For the Rockwell "L" test a 0.64 cm (1/4-inch) steel ball is used. The reading of the scale is taken after the major load is applied and removed but the minor load is still in place. There are two scales (a red and black scale), the red scale used for steel balls while the black scale is used for diamond cones. The difference in the scale is a constant 30 hardness points. Generally, the working range for the scales is between 0 and 100 as with the durometer test. The hardest materials are closer to 100 while the softer ones are closer to 0. The coupon thickness should be such that no bulges appear on the sides or back of the coupon. The coupon used in this project met this criterion. As with the Shore "D" test, three readings on a single coupon were averaged into a single number.

## Applying the Hardness Test to A/C Pipe Coupons

In order to determine whether either of these two hardness tests could be applied to A/C pipe, 12 A/C pipe sections or coupons were prepared and sent to Northwest Laboratories of Seattle, a materials testing laboratory. These coupons were approximately 5 cm by 5 cm (2-inches by 2-inches) and were designated samples A1 to A4, B1 to B4 and C1 to C4. Samples from pipe A were obtained from a 6-inch A/C pipe removed from 9200 Northesast 34th Street in Bellevue on Februry 23, 1981. At this point in the distribution system, Tolt water should have been present for most if not all of the year. Sample B was obtained from an unknown 15 cm (6 inch) A/C pipe section which had been previously removed from some point within the Bellevue distribution system. Sample C was obtained from a new 8-inch A/C pipe obtained from Bellevue's utility maintenance yard. The results from the hardness tests are shown in Table 10. Both test procedures yielded the same relative order, from softest to hardest, for all three pipe samples. As can be seen from Table 10, the spread of values obtained for each pipe section was quite narrow. Thus, it could be expected that results would be reproducible and show good relative hardness numbers from one sample to the next. A number of other test procedures including Brinnell hardness tests and various other Rockwell procedures were attempted, but proved undesirable due to problems such as excessive compression under applied loads or excessive rebound after removing the loads.

## Effects of Drying

One question which arose was the possible effect of moisture content on hardness test results from A/C test coupons. In order for this test procedure to be useful, it is necessary that the effect of moisture content be understood so that standard coupon preparation procedures may be outlined. Hence, a number of experiments were run to determine the effect of moisture content on hardness test results. Results from one such experiment are shown in Table 11. The data shown in Table 11 demonstrate that moisture content does not have a substantial effect on hardness test results. Typically, in this experiment and others, hardness test results increased in range of 5 to 10 percent with drying. In addition, hardness test results were very similar for air dried coupons and oven dried coupons. Thus, it would appear logical that either air dried or oven dried coupons may be utilized for hardness testing and reasonable results can be expected.

## SCANNING ELECTRON MICROSCOPE ANALYSIS

The scanning electron microscope was used for determining if zinc had deposited on the inner pipe surfaces and for measuring calcium loss from the asbestos-cement matrix. Each of the analyses presented below were performed by USEPA personnel using the methods of Millette (1983). A representative sample from each location was cut into three pieces. The first piece was approximately 1-inch long, the second was 1/2-inch long, and the remainder of the coupon made up the third piece. The first section was used in the Scanning Electron Microscope (SEM) for surface analysis. The second sample was embedded in a bakelite mount and the cross section used for Ca loss detection. All cutting was done under wet conditions using a glass cutting wheel and the sample was wrapped in parafilm during cutting to protect the surface of the pipe.

### X-ray Analysis of the Pipe Surface

A representative section of each piece of asbestos-cement test pipe removed from the ground at the end of the field testing was cut for surface analyses. The mortar-lined pipe was prepared by prying off the mortar coating and mounting it on a stub using low resistance contact cement. The uncoated pipe was placed in the SEM on a specially constructed holder to support the larger sample. All samples were analyzed using an ETEC scanning electron microscope along with an Ortec X-ray dispersion analysis system. An accelerating voltage of 20KV and a working distance of 13 to 17 mm were used. Five positions were analyzed at 100X for 100 sec live time. The positions picked formed the corners of a square and its middle. The area for each analysis was 0.8 mm by 0.8 mm. A sixth position at the center position was repeated at 20X for 200 sec live time and covered an area of 4 mm by 4 mm to get an overall average surface for analysis. The results of the five positions analyzed at 100X were averaged and plotted as energy vs. counts. The strength of the peak roughly suggests the surface composition of elements with atomic numbers above 10.

### Line Scans for Calcium Loss

Calcium loss analysis were done on pipe coupons removed from the pilot plant during phase 1A and on pipe sections removed from the ground at the end of the field testing. Each of the pieces cut for line scan analysis was mounted in bakelite. A few of the mortar-lined samples tended to split between the mortar coating and the A/C pipe. These were recut and only sample D3 separated again. The split was picked up on the line scan but both Si and Ca follow the drop, therefore, it does not affect the Ca loss data. Each bakelite was ground down, first using a grinder, then with successive wet sandings using 180, 320, 400, 600 grit paper. The cross section was scanned for Si, then Ca. The scans were plotted on the same axis and compared. Scan time was 500 seconds across a 4 mm long by 4 mm wide section. The scans paralleled each other if no Ca loss had occurred. The minimum detectable calcium loss was approximately 0.1 mm.

## TABLE 10

## INITIAL HARDNESS TEST RESULTS FOR A/C COUPONS (3/25/81)

**Tests Performed by Northwest Laboratories of Seattle, Inc.**

| Sample Number | Description | Shore "D" Hardness | Rockwell Hardness L Scale |
|---|---|---|---|
| A-1 | 6" A/C Pipe | 67 | 7 |
| A-2 | 9200 NE 34th | 65 | 10 |
| A-3 | | 66 | 5 |
| A-4 | | 64 | 14 |
| Average | | 65.5 | 9.0 |
| Std. Dev. | | 1.29 | 3.92 |
| B-1 | 6" A/C Pipe | 68 | 64 |
| B-2 | Unknown | 74 | 60 |
| B-3 | Location | 67 | 65 |
| B-4 | | 73 | 56 |
| Average | | 70.5 | 61.5 |
| Std. Dev. | | 3.51 | 4.11 |
| C-1 | 8" A/C Pipe | 79 | 99 |
| C-2 | New, Uninstalled | 81 | 100 |
| C-3 | Pipe | 82 | 98 |
| C-4 | | 78 | 98 |
| Average | | 80.0 | 98.7 |
| Std. Dev | | 1.83 | 0.96 |

## TABLE 11

## EFFECT OF MOISTURE CONTENT ON HARDNESS TEST EXPERIMENT RESULTS

| Test | Coupon | DRYING TIME |  |  |  |  |  |
|---|---|---|---|---|---|---|---|
|  |  | Initial | 24 hrs | 36 hrs | 4 days | 8days | 8 days plus 48 hrs @ 100°F |
| Shore "D" Hardness | T1-1 | 85 | 87 | 86 | 87 | 87 |  |
|  | T1-2 | 86 | 87 | 88 | 89 | 88 | 88 |
|  | T1-3 | 77 | 80 | 80[a] | 80 | 80[b] | 88 |
|  | T2-1 | 85 | 86 | 86 | 85 | 88 | 80[c] |
|  | T2-2 | 85 | 86 | 86 | 86 | 87 | 88 |
|  | T2-3 | 75 | 79 | 80[a] | 80 | 80[b] | 88 |
|  |  |  |  |  |  |  | 81[c] |
| Rockwell L Scale Hardness | T1-1 | 97 | 99 | 100 | 99 | 99 |  |
|  | T1-2 | 92 | 95 | 95 | 95 | 95 | 102 |
|  | T1-3 | 96 | 97 | 97[a] | 97 | 98[b] | 97 |
|  | T2-1 | 92 | 95 | 97 | 98 | 99 | 98[c] |
|  | T2-2 | 96 | 97 | 97 | 97 | 98 | 101 |
|  | T2-3 | 96 | 96 | 97[a] | 97 | 97 | 100 |
|  |  |  |  |  |  |  | 98[c] |

All tests performed by Northwest Laboratories of Seattle.

[a] Actual drying time 48 hrs

[b] Actual drying time 7 days

[c] Actual drying time 7 days plus 48 hrs @ 100°F

# SECTION 6

# PHASE IA: DISTRIBUTION SYSTEM CHARACTERIZATION

## INTRODUCTION

In order to fully define the conditions which may lead to the deterioration of A/C pipe and subsequent release of asbestos fibers, the current study was designed to incorporate a survey of distribution system water quality and pipe conditions. Information on Bellevue's distribution system water quality was limited, and no quantitative data were available on pipe materials. Thus, the background work performed under this study was necessary to describe the existing conditions prior to instituting any type of control measure aimed at curtailing A/C pipe deterioration. In addition, other objectives included: (1) documentation of water quality changes which occur in Bellevue's distribution system based on an accurate statistical analysis of asbestos fiber increase across the distribution system for both the Tolt and Cedar sources, and (2) a means of assessing the condition of A/C pipe which has been exposed to the aggressive waters in Bellevue's system for the last 30 to 40 years.

A series of water quality tests was to provide a better understanding of changes that occurred in Bellevue's distribution system. Due to the complex nature of Bellevue's system and the two raw water sources supplied by the Seattle Water Department, it was possible to individually examine the effects of two different water qualities. Samples were isolated by properly choosing sampling locations in order to evaluate both Tolt and Cedar water prior to exposure to A/C pipe and after a similar detention time in the distribution system.

With data gathered in this manner, it is possible to compare and contrast the aggressive, corrosive natures of both Tolt and Cedar River and also to assess the changes in water quality and the possible degradation which results from exposure of A/C pipe to these waters.

## SAMPLING SITE SELECTION

In order to ascertain water quality changes within the distribution system, sampling sites were selected which could provide representative samples for both Tolt and Cedar River water prior to their entrance to Bellevue's distribution system and after reasonable exposure time. To judiciously select sampling sites, it was necessary to hydraulically model Bellevue's distribution system through computer network models. Through cooperation with Bellevue's comprehensive plan consultant ($CH_2M$ Hill) and the Seattle Water Department, network analyses were performed and preliminary sampling sites were selected.

A number of practical concerns entered into the selection of sampling sites, and the following rules governed final site selection:

- Dead end lines and hydrant connections should be avoided. These could result in elevated asbestos fiber counts and would not provide representative water quality data for the system as a whole.

- Sampling sites had to be conveniently located such that water quality personnel could easily gain access and obtain samples. Sampling sites should (to the greatest extent possible) employ polyethylene or PVC fittings so that mineral water quality would not be affected by the sampling arrangement itself.

- Sampling stations should flow 24 hours a day so that representative samples may easily be obtained.

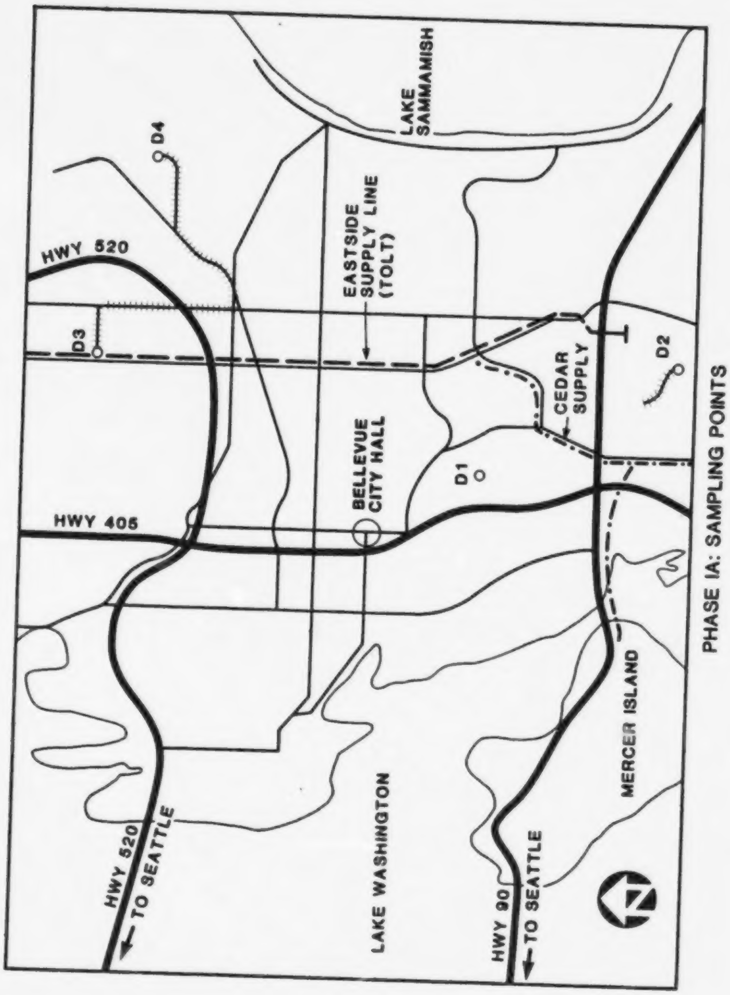
- Sampling stations for both the Tolt and Cedar River should provide approximately the same detention time within the distribution system in order to allow for comparisons between the two sources.

With these considerations in mind and with the assistance of City personnel, sampling sites were selected. Their locations are shown in Figure 2. Site D1 represents Cedar River water prior to entrance to Bellevue's A/C pipe network. This sampling station (Figure 3) is located in the Woodridge Pump Station and is the only location receiving exclusively Cedar water where it was possible to install a sampling station prior to exposure to A/C pipe.

The selection of a sampling site for Cedar River water within the A/C pipe network was limited since few pressure zones within Bellevue's system consistently receive Cedar water alone. Site D2 was selected and is shown in Figure 4. This station is located in the Somerset 550 pressure zone at the east end of Southeast 42nd Street. (The numbers of the presure zone, e.g., Somerset 550, relate to the hydraulic grade line of the zone). Operating conditions and discussions with Bellevue personnel indicated that this pressure zone was the best location for obtaining Cedar River water samples after exposure to the A/C network. Network analysis performed under average day conditions indicated that under average conditions, water at this point had 10 to 20 hours contact with A/C pipe, and had been exposed to over one half mile of A/C pipe.

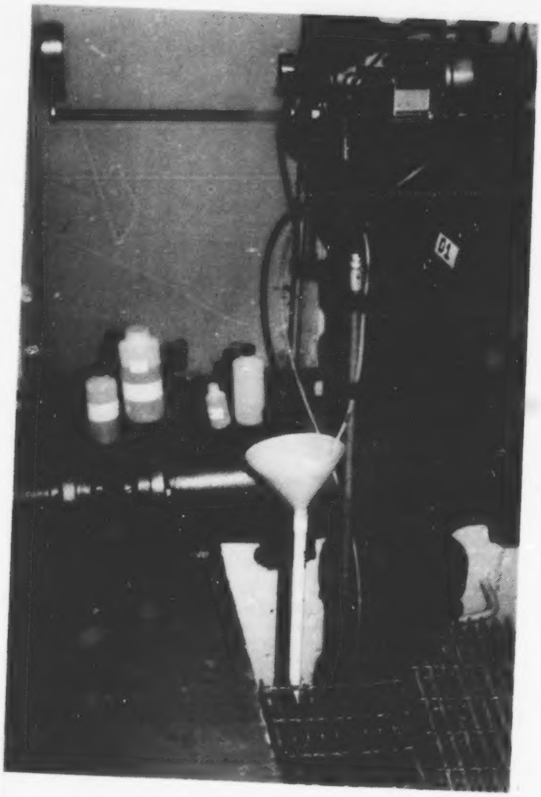
Unfortunately, D1 and D2 are not physically linked by pipelines because of the difficulty of finding a pipe network receiving exclusively Cedar water which also provided suitable locations for sampling sites. However, it is emphasized that site D1 and the network containing site D2 do receive the same Cedar water.

Figure 5 shows sampling station D3 which receives Tolt River water at the entrance to the A/C pipe network. It is located directly off the Seattle East Side Supply Line in the Northeast 40th Inlet Station. Sampling station D4, shown in Figure 6, is located on Northeast 169th Street in the northeast corner of Bellevue. This station is also an existing Seattle Water Department Safe Drinking Water Act sampling station. To arrive at this point, Tolt water must pass through three to four miles of A/C pipe with a residence time, under average day conditions, between 15 and 25 hours.


HWY 520
D4
D3
LAKE SAMMAMISH
EASTSIDE SUPPLY LINE (TOLT)
HWY 405
BELLEVUE CITY HALL
D1
CEDAR SUPPLY
D2
HWY 520
TO SEATTLE
LAKE WASHINGTON
MERCER ISLAND
HWY 90
TO SEATTLE
N

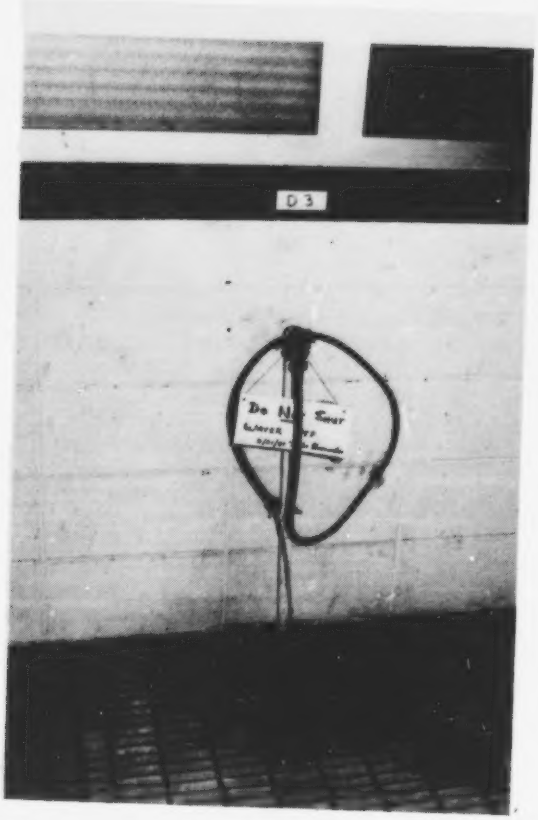
PHASE IA: SAMPLING POINTS

FIGURE 2

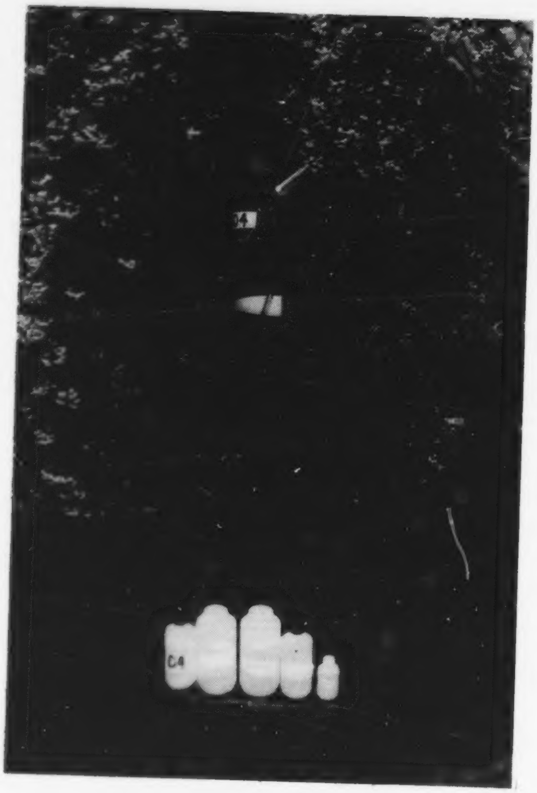


SAMPLING STATION D1: CEDAR RIVER WATER
PRIOR TO ENTRANCE TO BELLEVUE'S A/C PIPE NETWORK
(WOODRIDGE PUMP STATION)
FIGURE 3

**SAMPLING STATION D2: CEDAR RIVER WATER AFTER EXPOSURE TO THE A/C NETWORK FOR 15 HOURS UNDER AVEREAGE DAY CONDITIONS (SOMERSET 550 PRESSURE ZONE)**
**FIGURE 4**



SAMPLING STATION D3: TOLT RIVER WATER AT THE ENTRANCE TO THE A/C PIPE NETWORK (NE 40TH INLET STATION)
FIGURE 5



SAMPLING STATION D4: TOLT RIVER WATER
AFTER EXPOSURE TO A/C NETWORK
(NE 169TH ST., SEATTLE SDWA SAMPLING STATION)
SITE ALSO USED AS SAMPLE D5 FOR DUPLICATE ANALYSES
FIGURE 6

These four sampling sites provided controlled, limited access sampling stations which could be allowed to flow 24 hours a day. In addition, the length of the sampling line and the use of metallic or non-plastic materials were minimized to prevent inorganic contamination. Bellevue obtained a Seattle Water Department Safe Drinking Water Act sampling apparatus and installed it at sites D2 and D4. Sites D1 and D3 were sampled from simple spigots.

## ANALYSES

A variety of water quality analyses was performed for each sample collected from the distribution system. In addition, hardness tests were conducted for pipe samples removed from the distribution system.

### Water Quality Testing

Each of the four distribution system sampling sites were sampled at approximately monthly intervals for a period of twelve months under Phase IA. Each sample was collected by City of Bellevue personnel according to instructions described in Section 5. The temperature of each sample was measured at the time of collection. Samples were then delivered to a laboratory which was set up in an abandoned water treatment facility on Meydenbauer Hill in Bellevue. Samples were typically delivered within one to two hours of collection and analyzed for:

- pH in a closed system
- dissolved oxygen in a closed system
- chlorine residual

Each sample was then shipped to the JMM Environmental Research Laboratory via express mail, with a typical delivery time less than 24 hours. At the laboratory each sample was analyzed for:

- alkalinity
- total hardness
- total dissolved solids
- specific conductance
- sodium
- chloride
- fluoride
- nitrate
- potassium
- sulfate
- magnesium
- calcium
- zinc
- iron
- manganese
- silica
- chrysotile asbestos fiber count
- amphibole asbestos fiber count

The procedures and quality control checks practiced in these analyses are described in Section 5.

Duplicate asbestos samples were drawn from site D4 and labelled as site D5. This duplication continued for the first six months of this study; six paired samples were used to establish the reliability and reproducibility of asbestos measurements in the JMM laboratory. In addition, approximately 10 percent of all asbestos samples taken during the study were split with Dr. Edwin Boatman's laboratory at the University of Washington.

### Sampling Program

During the period of April 2, 1981 to March 3, 1982, a series of 10 samples was collected from sites D1 through D4. Six duplicate asbestos samples were drawn from site D4 (labelled site D5) from April to September 1981. The complete sampling schedule is shown in Table 12.

## RESULTS AND DISCUSSION

This section discusses the water qualities of the Tolt and Cedar systems separately, then compares the two systems. Finally, the results of hardness testing are presented.

### Tolt River System

Sampling sites D3 and D4 provided for sampling Tolt River water prior to the entrance to the A/C pipe distribution system and after approximately 15 hours detention time in the network. Ten paired samples for water quality analyses were collected between April 1981 and March 1982. However, during one of these sampling periods (March 1982), Cedar water was apparently supplied to the this section of Bellevue's distribution system, judging by water quality more characteristic of the Cedar than the Tolt. Hence, values obtained for March 1982 were not included in subsequent analyses. The remaining nine paired samples were analyzed for various water quality constituents. The complete set of water quality data is tabulated in Appendix A.

Table 13 presents a statistical summary of all water quality data in the Tolt system before and after exposure to A/C pipe. Appropriate statistical parameters, depending on the distribution of data, are shown for measures of the central tendency (average or arithmetic mean; geometric mean) and variability (standard deviation, spread factor, maximum and minimum). Subsequent Tables 14 through 16 provide summaries of parameters more likely to be associated with A/C pipe deterioration.

The sampling program demonstrated that the influent Tolt water was low in mineral content (average values of pH 5.7, 7.4 mg/L calcium, 5.1 mg/L alkalinity and 5.5 mg/L silica) and that deterioration was occurring in the A/C pipe network consistent with the hypothesis that it would be affected by aggressive water. After exposure to the A/C pipe, average values increased by 0.7 pH units, 1.7 mg/L calcium, 1.9 mg/L alkalinity and 1.6 mg/L silica. Paired t-test results in Table 17 indicate that these increases are statistically significant.

# TABLE 12

## WATER QUALITY OF TOLT WATER AT ENTRANCE TO DISTRIBUTION SYSTEM AND AFTER APPROXIMATELY 15 HOURS DETENTION IN THE A/C NETWORK[a]

| PARAMETER[b] | INFLUENT (SITE D3) | | | | EFFLUENT (SITE D4) | | | |
|---|---|---|---|---|---|---|---|---|
| | Avg. | | Max. | Min. | Avg. | | Max. | Min. |
| pH (no units) | 5.68 | 0.19 | 6.1 | 5.45 | 6.42 | 0.17 | 6.61 | 6.11 |
| Alk (as $CaCO_3$) | 5.06 | 3.35 | 11.8 | 1.9 | 6.96 | 1.73 | 9.6 | 4.0 |
| Calcium | 2.42 | 0.19 | 2.7 | 2.1 | 4.14 | 0.39 | 4.7 | 3.6 |
| Chrysotile (MFL) | 1.94[d] | 2.89[e] | 10.60 | 0.66 | 7.40[d] | 2.01[e] | 22.11 | 1.97 |
| Amphibole (MFL) | -[f] | -[f] | 1.71 | ND[c] | -[f] | -[f] | 0.39 | ND |
| L.I. (no units) | -4.96 | 0.28 | -4.55 | -5.51 | -3.70 | 0.27 | -3.37 | -4.15 |
| Zinc | 0.059 | 0.051 | 0.19 | 0.025 | 0.021 | 0.016 | 0.044 | ND |
| Silica | 5.49 | 0.38 | 6.0 | 4.8 | 6.12 | 0.33 | 6.5 | 5.6 |
| Iron | 0.088 | 0.049 | 0.18 | 0.037 | 0.11 | 0.04 | 0.17 | 0.074 |
| Magnesium | 0.50 | 0.24 | 1.1 | 0.3 | 0.33 | 0.31 | 1.1 | ND |
| Chloride | 1.39 | 0.59 | 2.1 | 0.4 | 1.72 | 0.48 | 2.4 | 0.9 |
| Sulfate | 1.96 | 0.89 | 2.9 | 0.4 | 2.28 | 0.81 | 3.6 | 0.76 |
| Nitrate | 0.22 | 0.23 | 0.8 | ND | 0.12 | 0.12 | 0.4 | ND |
| TDS | 14.4 | 2.2 | 18.0 | 10.0 | 18.4 | 4.1 | 28.0 | 14.0 |
| Hardness (as $CaCO_3$) | 8.1 | 0.9 | 10.0 | 7.0 | 11.8 | 1.5 | 14.7 | 10.0 |
| Manganese | 0.007 | 0.014 | 0.039 | ND | 0.005 | 0.011 | 0.03 | ND |
| Fluoride | 0.92 | 0.32 | 1.2 | 0.3 | 0.99 | 0.18 | 1.2 | 0.7 |
| Free Residual Chlorine | 0.27 | 0.26 | 0.6 | ND | 0.056 | 0.088 | 0.2 | ND |
| Temperature (°C) | 10.8 | 3.3 | 15.0 | 5.0 | 13.9 | 4.7 | 20.0 | 6.0 |
| Dissolved Oxygen | 10.5 | 2.5 | 14.5 | 6.0 | 10.5 | 1.7 | 13.0 | 7.3 |

[a] Values obtained for 9 samples collected between April, 1981 and January, 1982.

[b] All units mg/l except where noted

[c] None detected

[d] Geometric Mean

[e] Spread Factor

[f] Insufficient Non-zero Data

## TABLE 13

## DISTRIBUTION SYSTEM CHARACTERIZATION PHASE I, PART A - SAMPLING PROGRAM

| Date | Site | | | | |
|---|---|---|---|---|---|
| | D1 | D2 | D3 | D4 | D5* |
| 4/2/81 | 1,2,3** | 1,2,3 | 1,2,3 | 1,2,3 | 3 |
| 5/6/81 | 1,2,3,4 | 1,2,3,4 | 1,2,3,4 | 1,2,3 | 3 |
| 6/3/81 | 1,2,3 | 1,2,3 | 1,2,3 | 1,2,3 | 3 |
| 7/8/81 | 1,2,3 | 1,2,3 | 1,2,3,4 | 1,2,3,4 | 3 |
| 8/5/81 | 1,2,3 | 1,2,3 | 1,2,3 | 1,2,3 | 3 |
| 9/2/81 | 1,2,3 | 1,2,3 | 1,2,3 | 1,2,3 | 3 |
| 10/7/81 | 1,2 | 1,2 | 1,2,3 | 1,2,3 | - |
| 11/4/81 | 1,2,3 | 1,2,3 | 1,2,3 | 1,2,3 | - |
| 12/2/81 | 3 | 3,4 | - | - | - |
| 1/8/82 | 1,2,3 | 1,2,3 | 1,2,3 | 1,2,3 | - |
| 3/3/82 | 1,2,3 | 1,2,3 | 1,2,3 | 1,2,3,4 | - |

* Note: Sampling Sites D5 and D4 are the same; duplicate asbestos samples were collected.

** SAMPLE CODE

1 = Minerals sample (to JMM), 500 ml container
2 = Metals sample (to JMM), 125 ml container
3 = Asbestos sample (to JMM), one liter container
4 = Asbestos sample (to University of Washington), one liter container

## TABLE 14

## ASBESTOS FIBER CONCENTRATION CHANGES ACROSS THE TOLT DISTRIBUTION SYSTEM

| MONTH | INFLUENT TOLT WATER (SITE D3) Amphibole (MFL) | INFLUENT TOLT WATER (SITE D3) Chrysotile (MFL) | EFFLUENT TOLT WATER (SITE D4) Amphibole (MFL) | EFFLUENT TOLT WATER (SITE D4) Chrysotile (MFL) |
|---|---|---|---|---|
| 1 | 1.71 | 6.95 | 0.39 | 9.44 |
| 2 | ND | 1.57 | ND | 3.72 |
| 3 | ND | 4.33 | ND | 7.09 |
| 4 | ND | 0.66 | ND | 1.97 |
| 5 | ND | 0.44 | ND | 7.00 |
| 6 | ND | 10.6 | ND | 22.1 |
| 7 | ND | 1.14 | ND | 12.8 |
| 8 | ND | 1.76 | ND | 10.0 |
| 9 | -[b] | - | - | - |
| 10 | ND | 1.32 | ND | 6.83 |
| 11 | - | - | | |
| 12 | ND[a] | 1.46[a] | ND[a] | 4.63[a] |
| Geometric Mean | c | 1.94 | c | 7.40 |
| Spread Factor | — | 2.89 | — | 2.01 |

[a] Cedar Water; values not used in average

[b] Samples not taken

[c] Insufficient Data

ND denotes "None Detected"

## TABLE 15

## pH, LANGELIER INDEX, AND ALKALINITY CHANGES ACROSS THE TOLT DISTRIBUTION SYSTEM

| MONTH | INFLUENT TOLT WATER (SITE D3) | | | EFFLUENT TOLT WATER (SITE D4) | | |
|---|---|---|---|---|---|---|
| | pH | L.I. | Alk.[a] | pH | L.I. | Alk.[a] |
| 1 | 5.60 | -4.97 | 6.9 | 6.50 | -3.69 | 8.3 |
| 2 | 5.60 | -4.72 | 11.8 | 6.61 | -3.37 | 9.6 |
| 3 | 5.78 | -5.08 | 2.6 | 6.40 | -3.82 | 6.2 |
| 4 | 5.73 | -4.55 | 8.3 | 6.54 | -3.44 | 8.0 |
| 5 | 5.77 | -4.74 | 5.0 | 6.46 | -3.50 | 8.0 |
| 6 | 5.50 | -5.08 | 4.0 | 6.32 | -3.62 | 7.0 |
| 7 | 5.77 | -5.06 | 2.3 | 6.48 | -3.62 | 6.4 |
| 8 | 5.45 | -5.51 | 1.9 | 6.11 | -4.15 | 5.1 |
| 9 | 5.52 | - | - | 6.15 | - | - |
| 10 | 6.10 | -4.89 | 2.7 | 6.58 | -4.05 | 4.0 |
| 11 | - | - | - | - | - | - |
| 12 | 6.67[b] | -3.24[b] | 12.7[b] | 7.02[b] | -2.75[b] | 13.5[b] |
| Avg. | 5.68 | -4.96 | 5.06 | 6.42 | -3.70 | 6.96 |
| Std. Dev. | 0.19 | 0.28 | 3.35 | 0.17 | 0.27 | 1.73 |

[a] mg/l as $CaCO_3$

[b] Cedar Water; values not used in average

# TABLE 16

## CALCIUM, SILICA, AND HARDNESS CONCENTRATION[a] CHANGES ACROSS THE TOLT DISTRIBUTION SYSTEM

| | INFLUENT TOLT WATER (SITE D3) | | | EFFLUENT TOLT WATER (SITE D4) | | |
|---|---|---|---|---|---|---|
| MONTH | Ca | Silica | Hardness[b] | Ca | Silica | Hardness[b] |
| 1 | 2.2 | 6.0 | 10 | 4.1 | 6.4 | 15 |
| 2 | 2.1 | 6.0 | 7 | 4.7 | 6.5 | 13 |
| 3 | 2.4 | 5.3 | 8 | 3.6 | 5.7 | 11 |
| 4 | 2.6 | 5.5 | 9 | 4.1 | 6.5 | 11 |
| 5 | 2.4 | 5.7 | 8 | 3.9 | 6.1 | 12 |
| 6 | 2.4 | 5.4 | 8 | 4.5 | 6.3 | 12 |
| 7 | 2.5 | 5.2 | 7 | 4.3 | 5.6 | 11 |
| 8 | 2.7 | 5.5 | 8 | 4.5 | 6.0 | 12 |
| 9 | - | - | - | - | - | - |
| 10 | 2.5 | 4.8 | 8 | 3.6 | 6.0 | 10 |
| 11 | - | - | - | - | - | - |
| 12 | 5.7[c] | 9.3[c] | 18[c] | 6.9[c] | 8.9[c] | 19[c] |
| Avg. | 2.42 | 5.49 | 8.1 | 4.14 | 6.12 | 11.8 |
| Std. Dev. | 0.19 | 0.38 | 0.9 | .039 | 0.33 | 1.5 |

[a] All values in mg/l

[b] mg/l as $CaCO_3$

[c] Cedar Water; values not used in average

## TABLE 17

## STATISTICAL TESTING (PAIRED-T) OF CHANGES IN WATER QUALITY CONSTITUENTS ACROSS THE TOLT DISTRIBUTION SYSTEM

| Parameter | T Statistic | Mean Difference | Std Dev Difference | Degrees of Freedom | Significance[a] @ 5% or Better |
|---|---|---|---|---|---|
| Temperature | 6.489 | 3.333 | 1.541 | 08 | S |
| Alkalinity | 2.546 | 1.975 | 2.194 | 07 | S |
| Langelier Index | 32.426 | 1.313 | .114 | 07 | S |
| Hardness | 8.957 | 3.838 | 1.212 | 07 | S |
| pH | 17.133 | .761 | .133 | 08 | S |
| Total Diss. Solids | 3.152 | 4.375 | 3.926 | 07 | S |
| Calcium | 11.906 | 1.800 | .428 | 07 | S |
| Magnesium | -3.564 | -.175 | .139 | 07 | S |
| Iron | 1.875 | .031 | .047 | 07 | NS |
| Manganese | .146 | .001 | .014 | 07 | NS |
| Silica | 6.505 | .563 | .245 | 07 | S |
| Zinc | -2.282 | -.039 | .049 | 07 | S |
| Chloride | 1.208 | .250 | .586 | 07 | NS |
| Fluoride | -.144 | -.010 | .196 | 07 | NS |
| Sulfate | .809 | .142 | .498 | 07 | NS |
| Nitrate | -2.758 | .125 | .128 | 07 | S |
| Free Chlorine | -2.862 | -.213 | .210 | 07 | S |
| Chrysotile[b] | 4.68 | 3.82[c] | 2.36[c] | 07 | S |
| Amphibole | -[d] | -[d] | -[d] | 07 | NS |
| Diss. Oxygen | -1.209 | -.378 | .938 | 08 | NS |

[a] S = Significant; NS = Not Significant

[b] Based on log-normal distribution

[c] Geometric means of increase and spread factor

[d] Insufficient non-zero data

Note: Critical Values of T-Statistic at the 5% significance level are ± 1.895 at 7 degrees of freedom and ± 1.860 at 8 degrees of freedom.

Data contained in Table 15 also demonstrate that the Langelier Index at the influent to the Tolt portion of the water distribution system is highly negative and confirm the conclusion that the Tolt River supply can be regarded as extremely aggressive. The Langelier Index is consistently low with observed values ranging from a minimum of -5.51 to a maximum of -4.55. Data shown in Table 15 indicate that the Langelier Index increases consistently across the distribution system by an average value of 1.26, and the water becomes less aggressive with regard to A/C pipe as it passes through the A/C network. As was discussed previously, the Langelier Index is not a direct measure of a water's aggressiveness. However in attacking A/C pipe, Tolt water picks up constituents such as calcium which are measured by the L.I.

Asbestos fiber counts obtained for paired samples indicate that fiber levels also increase across the distribution system. Chrysotile fiber counts (Table 14) increased from site D3 to D4 for each paired set of samples drawn. On the average, (using geometric mean because asbestos data follow a log-normal distribution) chrysotile fiber levels increased by 5.5 million fibers per liter (MFL). The total chrysotile fiber count increased by over 100 percent, on the average, across the network.

Amphibole fiber data, also shown in Table 14, indicate that amphibole fibers are not released in detectible quantities to Bellevue's distribution system. This finding is consistent with previous studies and is indicative of the fact that amphibole fibers are not used during the manufacture of A/C pipe.

Table 17 presents the results of paired-T tests performed to determine the statistical significance of the observed increases or decreases of water quality constituents for the Tolt River system. Results indicate that all the parameters expected to increase with exposure to A/C pipe did indeed increase in statistically significant amounts in the Tolt system including alkalinity, Langelier Index, hardness, pH, TDS, calcium, silica, and chrysotile fiber count. Statistical tests were performed at the 5 percent significance level.

Constituents which showed a significant decrease across the distribution system included magnesium, zinc, nitrate and (as might be expected) free residual chlorine. Of this second group, the most interesting to examine is the observed decrease in zinc across the distribution system. This decrease was observed despite the fact that influent zinc concentrations averaged only 0.06 mg/L and the pH within the system was at a level much lower than would be expected for the precipitation of zinc, either in the form of zinc-hydroxy-carbonate or other forms of zinc. Previous computer modeling of the Tolt water did not predict precipitation of any zinc solids at naturally occurring pH levels and, thus, the nature of this decrease in zinc across the network is not understood. Precipitation of any zinc related solids may, however, aid in protection of the A/C pipe and could help to explain the fact that Tolt and Cedar waters (as will be discussed later) did not exhibit vastly different corrosive properties despite Langelier Indices that differ by almost three units.

### Cedar River System

Ten paired samples were obtained for the Cedar River system between April 1981 and March 1982, as with the Tolt system. However, during one sampling period (October 1981) Tolt water was apparently influent to the portion of the distribution system

(Somerset 550 Zone) sampled for Cedar River water. The remaining nine paired samples were used for Cedar River analyses in a similar fashion as presented for the Tolt River system. Each of these samples was again analyzed for 20 water quality constituents. The average, standard deviation, maximum observed value and minimum observed value for both influent and effluent sampling are shown in Table 18. Specific data obtained for calcium, silica, hardness, pH, Langelier Index, alkalinity, amphibole fiber count and chrysotile fiber counts are shown in Tables 19, 20 and 21. The complete set of water quality data is tabulated in Appendix A.

pH data, as shown in Table 20, indicate that the pH in the Cedar River system increased an average of 0.82 pH units across the distribution system. The standard deviation of this increase is approximately 0.55. While pH increased in eight of nine paired samples, the standard deviation observed for the increase was somewhat higher than that for the Tolt system. The increases for Langelier Index and alkalinity were approximately 1.0 units and 3.6 mg/L, respectively. Thus, the observed increase in alkalinity was greater for the Cedar system than for the Tolt. Data shown in Table 21 indicate that calcium increased across the Cedar distribution system by approximately 1.11 mg/L. Again, all nine of the paired observations demonstrated an increase in calcium concentration. Silica increased across the Cedar system to a lesser extent than in the Tolt system. However, the data do show a regular silica concentration increase across the distribution system, with an average increase of approximately 0.25 mg/L. Each of the increases mentioned was found to be statistically significant as shown in Table 22.

Table 19 demonstrates that chrysotile fiber counts also increased in the Cedar distribution system with few exceptions. On the average, chrysotile fiber counts increased by approximately 0.8 MFL, or roughly doubled, within the system. Of the nine paired samples analyzed, eight showed an increase across the system. Again, data contained in Table 19 indicate that amphibole fibers are not present either in the influent Cedar water or in Cedar water after exposure to A/C pipe. The reduced increase in fiber count (as compared with the Tolt) across the Cedar distribution system is consistent with the lower dissolution rates observed for calcium and silica.

Table 22 presents the results of statistical testing of changes in water quality constituents across the Cedar distribution system. As shown in Table 22, the following constituents demonstrated statistically significant increases with exposure to A/C pipe in the Cedar distribution sytem: temperature, alkalinity, Langelier Index, hardness, pH, calcium, silica and Chrysotile fiber count. The following constituents showed significant decreases across the system: magnesium, chloride, nitrate and free residual chlorine. Since chloride showed an increase in the Tolt system and a decrease in the Cedar system, it is not felt that the observed differences are truly meaningful. The observed decreases in nitrates for both the Cedar and Tolt systems are probably an artifact since nitrate levels were so low.

All of the major parameters regarding A/C pipe corrosion did show statistically significant increases across the system indicating that the pipe wall is being attacked and dissolved, to some degree, by the aggressive Cedar water. The fact that the magnitude of those changes is typically lower than those observed for the Tolt system would support the original assumption that Tolt water is more corrosive to A/C pipe than Cedar water.

## TABLE 18

## WATER QUALITY OF CEDAR WATER AT ENTRANCE TO DISTRIBUTION SYSTEM AND AFTER APPROXIMATELY 15 HOURS DETENTION IN THE A/C NETWORK[a]

| PARAMETER[b] | INFLUENT (SITE D1) |  |  |  | EFFLUENT (SITE D2) |  |  |  |
|---|---|---|---|---|---|---|---|---|
|  | Avg. | s | Max. | Min. | Avg. | s | Max. | Min. |
| pH (units) | 7.44 | 0.59 | 8.76 | 6.75 | 8.26 | 0.55 | 8.84 | 7.47 |
| Alk (as $CaCO_3$) | 16.4 | 3.64 | 22.0 | 9.6 | 20.0 | 4.0 | 26.0 | 14.5 |
| Calcium | 6.99 | 0.93 | 8.1 | 5.8 | 8.1 | 1.12 | 10.0 | 6.9 |
| Chrysotile (MFL) | 0.662[d] | 2.170[e] | 1.57 | 0.15 | 1.54 | 0.15 | 1.40[d] | 1.81[e] |
| Amphibole (MFL) | ND[c] | 0 | ND | ND | ND | 0 | ND | ND |
| L.I. (units) | -2.14 | 0.76 | -0.53 | -3.14 | -1.13 | 0.77 | -0.15 | -2.25 |
| Zinc | 0.031 | 0.039 | 0.121 | ND | 0.021 | 0.018 | 0.04 | ND |
| Silica | 9.74 | 0.76 | 11.0 | 8.8 | 9.99 | 0.72 | 11.0 | 9.0 |
| Iron | 0.04 | 0.03 | 0.058 | ND | 0.042 | 0.029 | 0.081 | ND |
| Magnesium | 1.02 | 0.16 | 1.4 | 0.9 | 0.79 | 0.33 | 1.3 | 0.018 |
| Chloride | 2.58 | 0.59 | 3.3 | 1.5 | 2.33 | 0.59 | 3.0 | 1.4 |
| Sulfate | 2.03 | 0.9 | 3.8 | 0.91 | 1.75 | 0.67 | 2.8 | 0.56 |
| Nitrate | 0.131 | 0.099 | 0.3 | ND | 0.097 | 0.083 | 0.2 | ND |
| TDS | 35.6 | 8.13 | 45.0 | 21.0 | 37.8 | 6.7 | 48.0 | 28.0 |
| Hardness (as $CaCO_3$) | 21.6 | 2.4 | 25.0 | 18.0 | 23.9 | 2.7 | 29.0 | 21.0 |
| Manganese | 0.004 | 0.008 | 0.023 | ND | 0.007 | 0.009 | 0.021 | ND |
| Fluoride | 0.96 | 0.26 | 1.5 | 0.6 | 0.93 | 0.26 | 1.1 | 0.5 |
| Free Residual Chlorine | 0.44 | 0.29 | 0.9 | ND | 0.33 | 0.23 | 0.6 | ND |
| Temperature (°C) | 12.8 | 4.4 | 19.0 | 7.0 | 14.2 | 5.3 | 22.0 | 7.0 |
| Dissolved Oxygen | 10.4 | 2.4 | 13.6 | 5.9 | 10.0 | 2.2 | 13.8 | 6.6 |

[a] Values obtained for 9 samples collected between April, 1981 and March, 1982.

[b] All units mg/l except where noted.

[c] None Detected

[d] Geometric Mean

[e] Spread Factor

## TABLE 19

## ASBESTOS FIBER CONCENTRATION CHANGES ACROSS THE CEDAR DISTRIBUTION SYSTEM

| MONTH | INFLUENT CEDAR WATER (SITE D1) Amphibole (MFL) | INFLUENT CEDAR WATER (SITE D1) Chrysotile (MFL) | EFFLUENT CEDAR WATER (SITE D2) Amphibole (MFL) | EFFLUENT CEDAR WATER (SITE D2) Chrysotile (MFL) |
|---|---|---|---|---|
| 1 | ND | 0.26 | ND | 0.79 |
| 2 | ND | 0.66 | ND | 1.97 |
| 3 | ND | 1.57 | ND | 0.49 |
| 4 | ND | 0.66 | ND | 2.46 |
| 5 | ND | 0.66 | ND | 1.80 |
| 6 | ND | 1.54 | ND | 2.30 |
| 7 | - | - | - | - |
| 8 | ND | 0.88 | ND | 2.19 |
| 9 | ND[a] | 1.90[a] | ND[a] | 3.29[a] |
| 10 | ND | 0.15 | ND | 0.73 |
| 11 | - | - | - | - |
| 12 | ND | 1.02 | ND | 1.65 |
| Geometric Mean | _[b] | 0.662 | _[b] | 1.40 |
| Spread Factor | _[b] | 2.170 | _[b] | 1.81 |

[a] Tolt Water; values not used in average

[b] Insufficient non-zero data

ND denotes None Detected

# TABLE 20

## pH, LANGELIER INDEX, AND ALKALINITY CHANGES ACROSS THE CEDAR DISTRIBUTION SYSTEM

| | INFLUENT CEDAR WATER (SITE D1) | | | EFFLUENT CEDAR WATER (SITE D2) | | |
|---|---|---|---|---|---|---|
| MONTH | pH | L.I. | Alk.[a] | pH | L.I. | Alk.[a] |
| 1 | 7.18 | -2.45 | 17.8 | 7.95 | -1.59 | 18.8 |
| 2 | 7.20 | -2.47 | 16.1 | 8.45 | -1.08 | 16.6 |
| 3 | 7.44 | -2.20 | 16.1 | 8.84 | -0.58 | 19.9 |
| 4 | 7.91 | -1.54 | 17. | 8.76 | -0.48 | 23. |
| 5 | 8.76 | -0.53 | 19. | 8.54 | -0.53 | 25. |
| 6 | 7.40 | -1.83 | 22. | 8.83 | -0.15 | 26. |
| 7 | 5.83[b] | -4.87[b] | 2.7[b] | 6.92[b] | -3.06[b] | 7.3[b] |
| 8 | 7.03 | -2.40 | 18. | 8.03 | -1.27 | 20. |
| 9 | 5.74[b] | - | - | 6.58[b] | - | - |
| 10 | 7.27 | -2.68 | 9.6 | 7.47 | -2.25 | 16.2 |
| 11 | - | - | - | - | - | - |
| 12 | 6.75 | -3.14 | 12.3 | 7.47 | -2.24 | 14.5 |
| Avg. | 7.44 | -2.14 | 16.4 | 8.26 | -1.13 | 20.0 |
| Std. Dev. | 0.59 | 0.76 | 3.64 | 0.55 | 0.77 | 4.0 |

[a] mg/l as $CaCO_3$

[b] Tolt Water; values not used in average

## TABLE 21

## CALCIUM, SILICA, AND HARDNESS CONCENTRATION[a] CHANGES ACROSS THE CEDAR DISTRIBUTION SYSTEM

| | INFLUENT CEDAR WATER (SITE D1) | | | EFFLUENT CEDAR WATER (SITE D2) | | |
|---|---|---|---|---|---|---|
| MONTH | Ca | Silica | Hardness[b] | Ca | Silica | Hardness[b] |
| 1 | 6.7 | 10.1 | 22.5 | 7.4 | 10.2 | 23.8 |
| 2 | 6.2 | 10.3 | 19. | 7.4 | 10.1 | 22. |
| 3 | 6.2 | 8.8 | 20. | 7.5 | 9.0 | 22. |
| 4 | 6.8 | 11. | 21. | 7.8 | 11. | 23. |
| 5 | 8.4 | 10. | 25. | 8.8 | 11. | 25. |
| 6 | 7.9 | 9.9 | 24. | 10. | 10. | 29. |
| 7 | 2.9[c] | 5.3[c] | 8.[c] | 4.7[c] | 5.4[c] | 13.[c] |
| 8 | 8.1 | 9.9 | 24. | 9.7 | 10. | 27. |
| 9 | - | - | - | - | - | - |
| 10 | 6.8 | 8.8 | 21. | 6.9 | 9. | 21. |
| 11 | - | - | - | - | - | - |
| 12 | 5.8 | 8.9 | 18. | 7.4 | 9.6 | 22. |
| Avg. | 6.99 | 9.74 | 21.6 | 8.10 | 9.99 | 23.9 |
| Std. Dev. | 0.93 | 0.76 | 2.4 | 1.12 | 0.72 | 2.7 |

[a] All values in mg/L

[b] mg/L as $CaCO_3$

[c] Tolt Water; values not used in average

## TABLE 22

### STATISTICAL TESTING (PAIRED-T) OF CHANGES IN WATER QUALITY CONSTITUENTS ACROSS THE CEDAR DISTRIBUTION SYSTEM

| Parameter | T Statistic | Mean Difference | Std Dev Difference | Degrees of Freedom | Significance[a] @ 5% or Better |
|---|---|---|---|---|---|
| Temperature | 3.266 | 1.333 | 1.225 | 08 | S |
| Alkalinity | 4.692 | 3.567 | 2.280 | 08 | S |
| Langelier Index | 5.551 | 1.008 | .545 | 08 | S |
| Hardness | 3.999 | 2.256 | 1.692 | 08 | S |
| pH | 4.499 | .822 | .548 | 08 | S |
| Total Diss. Solids | 1.785 | 2.222 | 3.734 | 08 | NS |
| Calcium | 5.263 | 1.111 | .633 | 08 | S |
| Magnesium | -2.393 | -.231 | .290 | 08 | S |
| Iron | .218 | .002 | .032 | 08 | NS |
| Manganese | 1.493 | .003 | .006 | 08 | NS |
| Silica | 1.976 | .244 | .371 | 08 | S |
| Zinc | -.866 | .011 | .037 | 08 | NS |
| Chloride | -2.052 | .244 | .357 | 08 | S |
| Fluoride | -.661 | .039 | .176 | 08 | NS |
| Sulfate | -1.667 | -.283 | .510 | 08 | NS |
| Nitrate | -2.097 | .034 | .049 | 08 | S |
| Free Chlorine | -2.826 | .112 | .113 | 07 | S |
| Chrysotile[b] | 2.78 | 2.11[c] | 2.24[c] | 08 | S |
| Amphibole | -------------Insufficient Non-Zero Data----- | | | | NS |
| Diss. Oxygen | -1.409 | -.400 | -.851 | 08 | NS |

[a] S = Significant; NS = Not Significant

[b] Based on log-normal distribution

[c] Geometric mean of increase and spread factor

Note: Critical Values of T-Statistic at the 5% significance level are ± 1.895 at 7 degrees of freedom and ± 1.860 at 8 degrees of freedom.

One additional item of note is that while a decrease in the average zinc concentration across the Cedar system was observed, it was not observed in statistically significant quantities. In addition, magnesium was observed to decrease significantly across both the Cedar and Tolt systems. While this decrease is not understood at present, it may be desirable to direct further effort in future studies to investigate the possibility of using magnesium compounds to precipitate a protective coating on A/C pipe.

## Comparison of Tolt and Cedar River Waters

Tables 23, 24 and 25 are included to present to the reader a comparative analysis of Tolt and Cedar River waters at the influent to the respective A/C distribution systems. Data for amphibole fiber counts, chrysotile fiber counts, pH, Langelier Index, alkalinity, calcium, silica, and hardness are shown in these tables. Most of this information has been discussed previously for the respective individual systems and will not be discussed further here. However, the data are presented in order to point out some of the basic differences between the two source waters and to facilitate a side-by-side review of the two influent waters.

These tables demonstrate that for Tolt River water, chrysotile fiber counts are typically much higher, pH is substantially lower, Langelier Index is more negative, alkalinity is much lower, calcium is much lower, silica is lower, and hardness is much lower than similar values obtained for the Cedar River system. The differences observed are consistent and exist throughout the year.

## Hardness Testing of Pipe Samples from the Distribution System

A number of pipe samples were collected from the distribution system whenever taps were made or breaks occurred in the system. The samples were collected and stored at the Meydenbauer laboratory facility, and a number of pipe samples were submitted to Northwest Laboratories of Seattle for hardness testing. As described in Section 5, the Shore "D" and Rockwell "L" scale hardness tests were utilized for testing pipe hardness. The purpose of this testing was two-fold: (1) to determine testing procedures which produced representative results describing the hardness of interior surfaces of A/C pipe, and (2) to run these tests on a number of samples from the Bellevue distribution sytem to determine the extent or degree of softening of A/C pipe within the network due to exposure to corrosive Tolt and Cedar River waters for the last 30 to 40 years.

Table 26 presents the results of hardness testing for coupons removed from the distribution system. Samples Nos. 300 and 400 were new, unused pipe. Results from them serve as references for comparison with results obtained for coupons removed from the distribution system (Samples Nos. 500 though 510). Values obtained for pipe coupons removed from the distribution system ranged from a low of 55 to a high of 79 using the Shore "D" hardness test versus a new pipe value of approximately 90. Hardness test results utilizing the Rockwell L scale hardness test on coupons removed from the distribution system ranged from a low of 22 (note that the value of -10 obtained from sample 506 was discarded due to interference with the tapered end of the pipe) to a high of 85 versus a new pipe value of approximately 106. Using the average hardness values and assuming that new pipe hardness today is representative of new

# TABLE 23

## COMPARISON OF ASBESTOS CONCENTRATIONS BY MONTH AT THE ENTRANCE TO THE DISTRIBUTION SYSTEM

| MONTH | CEDAR (SITE D1) | | TOLT (SITE D3) | |
|---|---|---|---|---|
| | Amphibole | Chrysotile | Amphibole | Chrysotile |
| | (MFL) | | (MFL) | |
| 1 | ND | 0.26 | 1.71 | 6.95 |
| 2 | ND | 0.66 | ND | 1.57 |
| 3 | ND | 1.57 | ND | 4.33 |
| 4 | ND | 0.66 | ND | 0.66 |
| 5 | ND | 0.66 | ND | 0.44 |
| 6 | ND | 1.54 | ND | 10.6 |
| 7 | - | - | ND | 1.14 |
| 8 | ND | 0.88 | ND | 1.76 |
| 9 | ND[a] | 1.90[a] | - | - |
| 10 | ND | 0.15 | ND | 1.32 |
| 11 | - | - | - | - |
| 12 | ND | 1.02 | ND[b] | 1.46[b] |
| Geometric Mean | –[c] | 0.662 | –[c] | 1.94 |
| Spread Factor | –[c] | 2.170 | –[c] | 2.89 |

[a] Tolt Water; values not used in average
[b] Cedar Water; values not used in average
[c] Insufficient Non-zero Data
ND denotes None Detected

## TABLE 24

## pH, LANGELIER INDEX, AND ALKALINITY BY MONTH FOR TOLT AND CEDAR INFLUENTS TO THE DISTRIBUTION SYSTEM

| | TOLT WATER (SITE D3) | | | CEDAR (SITE D1) | | |
|---|---|---|---|---|---|---|
| MONTH | pH | L.I. | Alk.[a] | pH | L.I. | Alk.[a] |
| 1 | 5.60 | -4.97 | 6.9 | 7.18 | -2.45 | 17.8 |
| 2 | 5.60 | -4.72 | 11.8 | 7.20 | -2.47 | 16.1 |
| 3 | 5.78 | -5.08 | 2.6 | 7.44 | -2.20 | 16.1 |
| 4 | 5.73 | -4.55 | 8.3 | 7.91 | -1.54 | 17. |
| 5 | 5.77 | -4.74 | 5.0 | 8.76 | -0.53 | 19. |
| 6 | 5.50 | -5.08 | 4.0 | 7.40 | -1.83 | 22. |
| 7 | 5.77 | -5.06 | 2.3 | 5.83[b] | -4.87[b] | 2.7[b] |
| 8 | 5.45 | -5.51 | 1.9 | 7.03 | -2.40 | 18. |
| 9 | 5.52 | - | - | 5.74[b] | - | - |
| 10 | 6.10 | -4.89 | 2.7 | 7.27 | -2.68 | 9.6 |
| 11 | - | - | - | - | - | - |
| 12 | 6.67[c] | -3.24[c] | 12.7[c] | 6.75 | -3.14 | 12.3 |
| Avg. | 5.68 | -4.96 | 5.06 | 7.44 | -2.14 | 16.4 |
| Std. Dev. | 0.19 | 0.28 | 3.35 | 0.59 | 0.76 | 3.64 |

[a] mg/L as $CaCO_3$

[b] Tolt Water; values not used in average

[c] Cedar Water; values not used in average

## TABLE 25

## COMPARISON OF CALCIUM, SILICA, AND HARDNESS CONCENTRATIONS[a] BY MONTH FOR TOLT AND CEDAR INFLUENTS TO THE DISTRIBUTION SYSTEM

| | TOLT (SITE D3) | | | CEDAR (SITE D1) | | |
|---|---|---|---|---|---|---|
| MONTH | Ca | Silica | Hardness | Ca | Silica | Hardness |
| 1 | 2.2 | 6.0 | 10 | 6.7 | 10.1 | 22.5 |
| 2 | 2.1 | 6.0 | 7 | 6.2 | 10.3 | 19. |
| 3 | 2.4 | 5.3 | 8 | 6.2 | 8.8 | 20. |
| 4 | 2.6 | 5.5 | 9 | 6.8 | 11. | 21. |
| 5 | 2.4 | 5.7 | 8 | 8.4 | 10. | 25. |
| 6 | 2.4 | 5.4 | 8 | 7.9 | 9.9 | 24. |
| 7 | 2.5 | 5.2 | 7 | 2.9[b] | 5.3[b] | 8.[b] |
| 8 | 2.7 | 5.5 | 8 | 8.1 | 9.9 | 24. |
| 9 | - | - | - | - | - | - |
| 10 | 2.5 | 4.8 | 8 | 6.8 | 8.8 | 21. |
| 11 | - | - | - | - | - | - |
| 12 | 5.7[c] | 9.3[c] | 18[c] | 5.8 | 8.9 | 18. |
| Avg. | 2.42 | 5.49 | 8.1 | 6.99 | 9.74 | 21.6 |
| Std. Dev. | 0.19 | 0.38 | 0.9 | 0.93 | 0.76 | 2.4 |

[a] All valves mg/L; hardness expressed as mg/L as $CaCo_3$

[b] Tolt Water; values not used in calculations

[c] Cedar Water; values not used in calculations

pipes 30 to 40 years ago, the rate of change in hardness is one to two points per year for Rockwell "L" hardness and 0.5 to one point per year for Shore "D" hardness.

Based upon this data it would appear that all of the pipe samples tested from the distribution system showed evidence of softening. With the limited testing that has been performed to date, it is impossible to make firm conclusions on what this softening indicates. However, one value of this approach is that with further development it may potentially offer a relatively simple, inexpensive means for managers of water supply systems to assess the relative conditions of different sections of the A/C pipe network. For example, one may conclude from the data shown in Table 26, that the areas of the distribution system from which samples 500 and 501 are obtained are in substantially poorer condition than those areas from which samples 509 and 510 were obtained.

As is noted in Table 26, a number of samples removed from the distribution system demonstrated a reddish-brown or brown, interior coating. This most likely is due to the precipitation of iron or manganese bearing materials. The sources of iron or manganese are not known with certainty, but could include earlier groundwater sources and/or iron pipe materials. The fact that the A/C pipe in many instances was also substantially softened would seem to indicate this iron or manganese precipitate has not substantially lessened the corrosion and degradation of the pipe wall. Any effect of the deposit on asbestos fiber release is uncertain at this point.

## CONCLUSIONS

The following conclusions may be drawn from Phase IA testing:

1. Calcium, Langelier Index, chrysotile fiber count, alkalinity, pH and silica increased in statistically significant quantities in both Tolt and Cedar distribution systems after exposure to A/C pipe.

2. Asbestos fibers appear to be released into the transported water in both systems, probably as a result of deterioration of the pipe wall from corrosive attack.

3. Hardness testing results indicate that the Shore "D" and Rockwell "L" scale hardness testing procedures are a viable means of assessing the relative condition of various sections of A/C pipe.

4. Tolt water is more aggressive with respect to A/C pipe than Cedar water.

5. A/C pipe in Bellevue's system has been physically softened when compared to new pipe hardness.

6. Significant quantities of pipe wall material apparently have been released to the transported water in both the Tolt and Cedar River systems.

## TABLE 26

## HARDNESS TESTING RESULTS[a] FOR COUPONS REMOVED FROM THE DISTRIBUTION SYSTEM

| Sample Number | Location | Shore "D" Hardness | Rockwell L Scale Hardness | Remarks |
|---|---|---|---|---|
| 300 | — | 89 | 108 | new pipe (unused) |
| 400 | — | 91 | 104 | new pipe (unused) |
| 500 | 16240 SE 9th | 57 | 37 | rust-red deposits, smooth interior |
| 501 | NE 2nd at Overlake Dr. | 55 | 51 | installed 1948, reddish-brown, rough |
| 502 | 166th at SE 35th | 68 | 39 | some brown deposits, smooth interior |
| 503 | 3440 NE 78th | 66 | 45 | some red deposits, smooth interior |
| 504 | 8015 NE 28th | 69 | 41 | installed 1943, dark brown |
| 505 | 4315 SE 134th | 76 | 65 | light tan, some roughness |
| 506 | 92 Ave NE at NE 34th | 77 | -10[b] | brown, smooth |
| 507 | 91st NE 10 | 70 | 22 | dark brown |
| 508 | Overlake Dr. at Upland | 68 | 61 | very dark brown, smooth |
| 509 | 2515-86 Ave NE | 72 | 64 | rough, white interior |
| 510 | 3104-124th SE | 79 | 85 | rough, white interior |

[a] All analyses performed by Northwest Laboratories of Seattle. All results are average of 3 readings

[b] Tapered end of pipe interfered with test

# SECTION 7

## PHASE IB: RECIRCULATION EXPERIMENTS

### INTRODUCTION

Concurrent with investigations of the distribution system previously described, laboratory analyses of corrosion and corrosion control were carried out at the Meydenbauer Hill facility in the City of Bellevue. In this phase of the work, eight experimental recirculation units were constructed and utilized to examine a variety of conditions for exposure of A/C test coupons to the aggressive waters distributed in Bellevue's system. Recirculation conditions, rather than flow-through, were used so that changes in water quality could be detected. This section describes the design and operation of the experimental units, the test conditions and control strategies examined in the eight experimental tanks, analyses performed during the experiments, and the sampling program or schedule which was carried out.

### APPARATUS DESIGN AND OPERATION

Eight tanks similiar to those described in Buelow et al. (1980) were fabricated and installed at the Meydenbauer facility. The tanks, recirculation lines, pumps, meters and sampling ports were composed entirely of non-metallic components. In previous EPA studies it had been determined that various metal constituents, such as iron and zinc, may provide protective coatings to A/C pipe under conditions that would normally be regarded as corrosive. Thus, in the current study it was desired to avoid this potential interference and the test units were designed such that the water contained within them was never exposed to metallic components. In addition, this eliminated the potential for contamination of water quality samples from the tanks due to corroding metal components. Figure 7 shows the configuration of each of the experimental tanks schematically.

Each tank used a floating cover system to recirculate water without exposure to the atmosphere. Figure 8 shows several of these units in place at the Meydenbauer Laboratory. 100 gallon graduated linear polyethylene (LPE) tanks were used. Floating covers were also fabricated of LPE material. Plastic pumps, (March Manufacturing Company, Model MDXT) were used for recirculation. Plastic water meters (Badger Recordall, Model 15) were used to record flow through the system in units of 2.8 liters (0.1 cubic foot). A typical pump and meter configuration is shown in Figure 9. Figure 10 shows the floating covers, the chemical feed port for addition of pH adjustment chemicals and chlorine, as well as the sample tap for collection of samples.

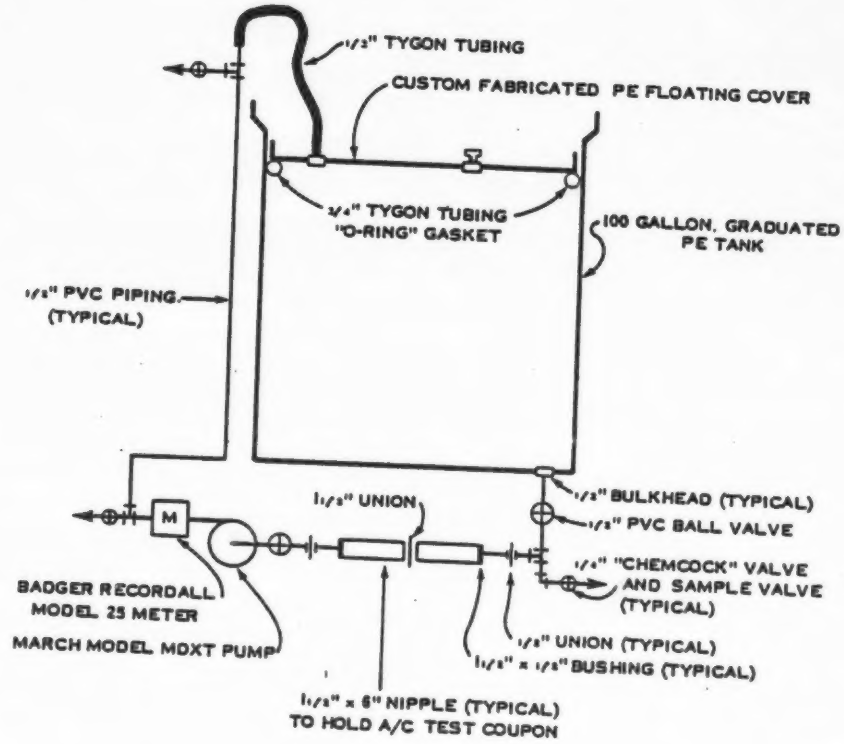
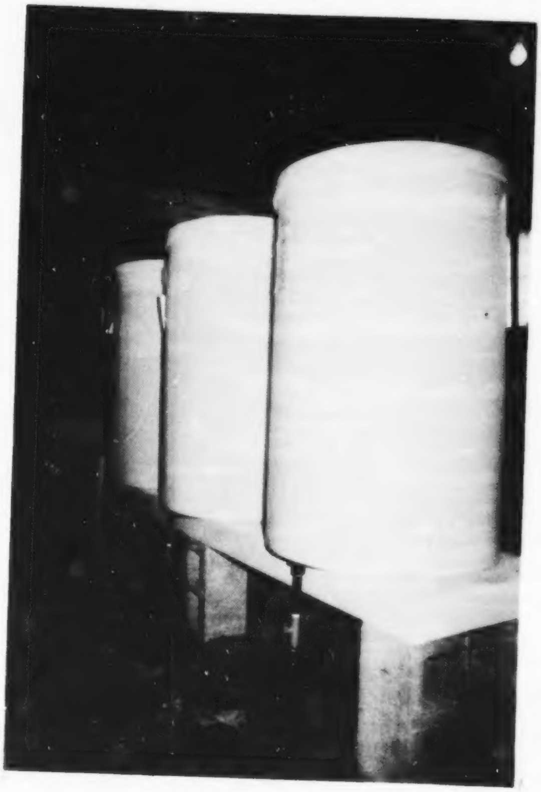
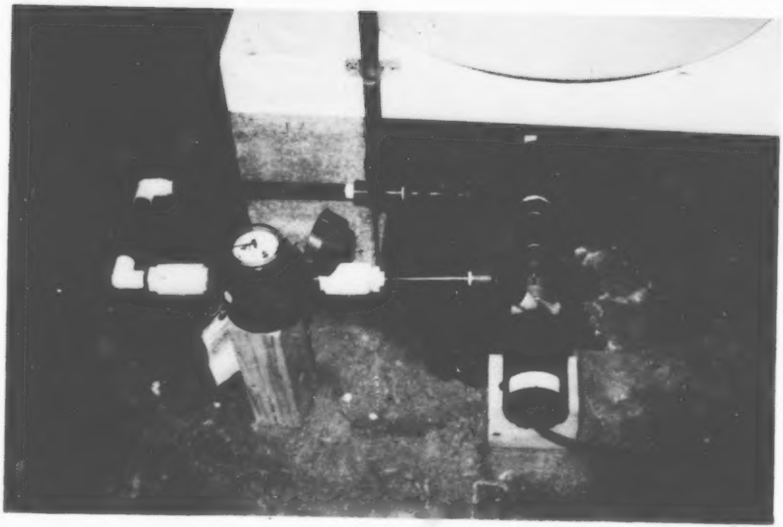

1/2" TYGON TUBING
CUSTOM FABRICATED PE FLOATING COVER
3/4" TYGON TUBING "O-RING" GASKET
100 GALLON, GRADUATED PE TANK
1/2" PVC PIPING (TYPICAL)
1 1/2" UNION
1/2" BULKHEAD (TYPICAL)
1/2" PVC BALL VALVE
1/4" "CHEMCOCK" VALVE AND SAMPLE VALVE (TYPICAL)
M
BADGER RECORDALL MODEL 25 METER
MARCH MODEL MDXT PUMP
1/2" UNION (TYPICAL)
1 1/2" x 1/2" BUSHING (TYPICAL)
1 1/2" x 6" NIPPLE (TYPICAL) TO HOLD A/C TEST COUPON

FIGURE 7

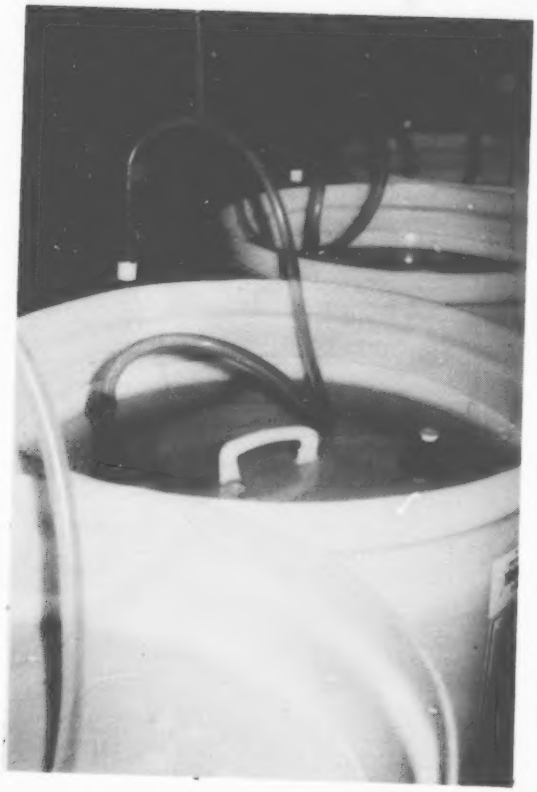
SCHEMATIC DIAGRAM OF RECIRCULATION TEST APPARATUS



EXPERIMENTAL TANKS 6, 7 AND 8 AT
MEYDENBAUER HILL LABORATORY
FIGURE 8



TYPICAL PUMP AND METER CONFIGURATION -
EXPERIMENTAL TANK APPARATUS
FIGURE 9



FLOATING COVERS, SHOWING CHEMICAL FEED PORT
AND SAMPLE TAP
FIGURE 10

Tolt River water was used in seven of the eight tanks examining corrosion control strategies for A/C pipe. A 3785-liter (1000-gallon) sample of Tolt water was delivered to the Meydenbauer Laboratory facility in a stainless steel water truck which had been thoroughly cleaned prior to pickup from the Northeast 40th Inlet Station. Thus, the water delivered to the Meydenbauer Laboratory was typical of Tolt River water influent to Bellevue's system during March of 1981.

During operation, conditions in the tanks were monitored at weekly intervals. Each week pH and chlorine residual were tested for each tank. In the two control tanks (containing raw Tolt and Cedar River water) pH was allowed to fluctuate. In the six tanks examining corrosion control strategies, however, pH was maintained at predetermined levels. The conditions examined in each of these tanks are fully discussed in the next section. pH measurements were made following the procedures outlined in Schock, et al. (1980), in which the pH was measured in a stoppered flask simulating conditions closed to the atmosphere in the tank. Sodium hydroxide and hydrochloric acid were used for pH adjustment during the course of the study. The use of sodium hydroxide and hydrochloric acid to adjust pH in the corrosion control strategy tanks affects the observed increases in alkalinity for those tanks as demonstrated later in this report. No ready alternative for adjusting pH without impacting alkalinity was available, however, and NaOH and HCl were employed due to their availability and ease of application. It should also be noted that after the first two months of the study, little pH adjustment was necessary and the amounts of HCl and NaOH added tended to balance each other to a large extent. For the most part, it was possible throughout the course of the study to maintain pH in the tanks to plus or minus 0.05 pH units of the desired value.

Chlorine residual was also monitored in each tank; to maintain conditions similiar to those in the distribution system, a free residual chlorine level of between 0.5 and 2 milligrams per liter was maintained. In addition, this residual was maintained to prevent biological growth within the tanks and possible bio-film which may coat the A/C test coupons. Observations on the tank pH, chlorine residual, meter reading, and other general observations were recorded in notebooks which provided historical data for operation of facilities over the life of the project.

## TEST CONDITIONS AND CONTROL STRATEGIES EXAMINED

Eight experimental units were fabricated and installed at Meydenbauer Laboratory as shown in Table 27. Based upon the fact that the Langelier Index, as well as the Aggressive Index and other means of assessing corrosivity, indicated that Tolt water was considerably more corrosive than Cedar River water, it was decided to examine corrosion control strategies utilizing Tolt water as representing the worst case conditions. For this reason, the corrosion control strategies examined herein utilized Tolt River water in tanks 3 through 8.

Tank 1 contained Cedar River water which was delivered to the laboratory site in 75.7 L (20 gallon) polyethylene buckets. Tank 2 contained Tolt River water delivered to the site by water truck. In tanks 1 and 2 no pH control or chemical addition was practiced other than adding chlorine to maintain a chlorine residual. In the two control tanks, four A/C test coupons, approximately 2.5-centimeters (1-inch) in width by

## TABLE 27

## EXPERIMENTAL TANK CONDITIONS

| Tank | Water Source | Corrosion Control Conditions |
|---|---|---|
| 1 | Cedar River Water | No control |
| 2 | Tolt River Water | No control |
| 3 | Tolt River Water | Proposed Seattle Corrosion Control Program (lime and soda ash addition, maintain pH at approximately 8.0) |
| 4 | Tolt River Water | Proposed Seattle Corrosion Control Program plus additional lime and soda ash addition, maintain pH at 9.0 |
| 5 | Tolt River Water | Proposed Seattle Corrosion Control Program, addition of zinc chloride (0.3 mg/L as Zn), maintain pH at 8.5 |
| 6 | Tolt River Water | Proposed Seattle Corrosion Control Program, addition of zinc chloride (0.6 mg/L as Zn), maintain pH at 8.0 |
| 7 | Tolt River Water | Proposed Seattle Corrosion Control Program, addition of sodium metasilicate (12.7 mg/L as $SiO_2$), maintain pH at 8.0 |
| 8 | Tolt River Water | Proposed Seattle Corrosion Control Program, addition of iron (III) salt ($FECl_3$) (0.2 mg/L as Fe), maintain pH at 8.0 |

15-centimeters (6-inches) in length, were inserted in the recirculation line; the coupons were removed and analyzed for hardness at 3, 6, 9 and 12 months exposure.

In tanks 3 through 8, which examined various corrosion control strategies, two A/C test coupons were inserted in each recirculation line and allowed to remain in the line through the entire operation of the test. These coupons were identical in size to those used in tanks 1 and 2. All A/C test coupons used in these experiments were obtained by cutting a portion of a new, unused section of 15-centimeters (6-inch) A/C pipe from the City's maintenance yard. The sides and back of each coupon were coated with a silicone-rubber sealant to eliminate exposure of the coupon to the recirculating water except for the interior face of the pipe wall.

Tank 3 modeled conditions which were to be typical in Bellevue's system after start-up of the then proposed Seattle Corrosion Control Program, consisting of lime and soda ash addition at the Tolt water supply and lime addition at the Cedar River water supply to provide water to Bellevue with a pH of approximately 8.0 in the distribution system. For the purposes of this test, 10 mg/L of soda ash and 1 mg/L of lime were added to tank 3. In addition, this dosage was also added to tanks 4 through 8 in order to provide the background conditions anticipated for Bellevue's system after startup of the Seattle Corrosion Control Program.

In tank 4 an additional 5 mg/L of soda ash and an additional 1 mg/L of lime was added. pH was maintained in this tank at 9.0 throughout the course of the study. The intent of the strategy examined in tank 4 was to examine theeffect of maintaining a slightly higher pH and less negative Langelier Index at mitigation of corrosion of A/C pipe. Maintaining a non-negative Langelier Index with Tolt water was not feasible as both alkalinity and calcium values are so low that it would be necessary to add substantial doses of soda ash and lime to provide for a positive Langelier Index. In additio, Tolt River water is poorly buffered such that pH would rise rapidly upon lime and soda ash addition; it would be necessaryto utilize hydrochloric or sulfuric acid to bring the pH back down to an acceptable level.

Tanks 5 and 6 used zinc chloride as a corrosion inhibitor in A/C pipe. As discussed in Section 2, the USEPA and others have investigated the use of zinc in various forms to establish a protective coating on the surface of A/C pipe in order to inhibit the dissolution of the pipe wall and the subsequent release of asbestos fibers. It has been theorized that the form of zinc is relatively unimportant with regard to protection of A/C pipe. In past studies, zinc forms such as zinc orthophosphate or zinc polyphosphate have been used. In this study, it was desired to investigate zinc chloride since this form of zinc is the least expensive form available and would not provide any nutrient input to nurture biological growth in open drinking water reservoirs.

The doses shown in Table 27 for tanks 5 and 6 were determined utilizing the program REDEQL.EPAK provided by EPA Cincinnati. Typical raw water data for Tolt River water was input to the program and saturation index information was calculated for a variety of zinc precipitates at various levels of zinc and pH. The results of this analysis indicated that zinc hydroxycarbonate would precipitate at a pH of 8.5 at a zinc concentration of approximately 0.2 mg/l. Thus, in tank 5, a more conservative zinc dose of approximately 0.3 mg/l was applied and pH was maintained at 8.5. Additional analyses utilizing this approach showed that at pH 8.0, zinc hydroxycarbonate solubility was exceeded at a zinc level of approximately 0.5 milligrams per liter. Thus, in tank 6 a zinc chloride dose of approximately 0.6 mg/l as zinc was added while pH was maintained at 8.0.

In tanks 5 and 6, the intent was to provide a zinc concentration of approximately 0.1 mg/l above levels predicted by computer modelling to exceed solubility.

Tank 7 investigated the use of sodium metasilicate corrosion inhibitor in Tolt River water, while tank 8 contained iron salts for corrosion inhibition in Tolt water. In both tanks 7 and 8, a pH of 8.0 was maintained throughout the course of the study and the chemical doses shown were determined based on past USEPA studies and previous corrosion studies performed in the Seattle area (Schock, et al. 1981, Buelow, et al. 1980, Kennedy Engineers, 1976).

## ANALYSES

During the course of Phase IB, water quality analyses were performed similar to Phase IA. Also, a series of tests were conducted to examine the condition of the test coupons were used in the recirculation tests.

### Water Quality Analyses

Water quality analyses performed on recirculation corrosion control investigations were similiar to those described in Section 6 for Phase IA of this report. Sampling procedures used were described in Section 5. pH, dissolved oxygen, chlorine residual and temperature were measured on-site in the Meydenbauer Laboratory by Bellevue personnel. Samples identical to those previously described for Phase IA of this work were sent to JMM's laboratory in Pasadena for analyses. Asbestos samples were drawn from each of the eight tanks upon start-up of the experiments, at the mid-point of the experimental progam, and at the end of the 48 week test period.

### Pipe Coupon Testing

The A/C test coupons used in this work were approximately 2.5 cm (1-inch) wide by 15 cm (6-inches) long. Each of the coupons was weighed prior to insertion in the test apparatus and then reweighed upon removal. This test was performed to see if any quantitative change in weight occurred either due to deposition of scale on the surface of the pipe or due to weight loss from leaching of calcium constituents of the pipe wall. All coupons were dried in a drying oven for approximately 8 to 12 hours at 70°C. Previous discussions with EPA personnel had indicated that they experienced problems in obtaining uniform weights from coupons dried at temperatures in excess of 100°C, wherein weight loss continued to occur with drying for up to 100 days. However, it is likely that this continued weight loss was due to some alteration of the basic properties of the material in the pipe wall rather than loss of free water. This type of problem did not appear in the weight change observations reported herein. However, all coupons were weighed uniformly and relative numbers should be accurate, regardless of any weight loss with drying.

In addition to being analyzed for weight loss, pipe coupons were periodically submitted to Northwest Laboratories of Seattle, Inc. for hardness testing by procedures described in Section 5. Coupons from the two control tanks (tanks 1 and 2) were removed at three month intervals, weighed and submitted for hardness testing. Each of the two coupons from tanks 3 though 8 (the corrosion control strategy investigation tanks) were removed at the completion of the 48 week test period and submitted to the laboratory for hardness testing.

### Sampling Program

The sampling schedule and program for water quality tests for the recirculation control experiments is shown in Table 28. Hardness tests and weight loss measurements were performed at intervals previously described.

## RESULTS AND DISCUSSION

This section consists of the following: a detailed discussion of results for each of the experimental tanks in terms of the salient water quality parameters (excluding asbestos); a discussion of the asbestos data obtained for all eight of the recirculation corrosion control experiments; and presentation of the results of physical testing (including hardness testing) of the A/C test coupons employed in the tanks.

### Correlation of Results

Prior to a discussion of the results of the experimental tank testing, it is first necessary to present some information with regard to the correlation of results from one test tank to another, since the conditions examined in each of the eight tanks were not identical for various reasons. In the control tanks (1 and 2), four A/C test coupons were mounted in the test coupon holding rack. One coupon was removed from each of the control tanks at three month intervals. Thus, each tank contained four coupons for the first 12 weeks, three coupons for the next 12 weeks, two coupons for the next 12 weeks, and one coupon for the last 12 weeks of the study period. To examine hardness and corrosion rates as a function of time, multiple coupons and sampling times were required since the coupons could not be re-inserted after removal for testing.

In the corrosion control strategy tanks (3 through 8), two coupons were mounted in each rack and remained exposed for the entire 48 week period of the testing program. The control strategy tanks were operated in this manner to facilitate direct comparisons between the results obtained from each of the six tanks.

Table 29 presents a means for correlation of results from one tank to another. The second column in Table 29 expresses total coupon exposure time in coupon-weeks, arrived at by multiplying the number of coupons exposed for each time interval. Thus, for tanks 3 through 8, the total coupon exposure time is the product of two coupons times 48 weeks or 96 coupon-weeks. The third column in Table 29 shows the average recirculation flow rate in each of the experimental tanks, obtained by dividing the total flow through each apparatus (as totalized by the flow meters) by the total minutes of operation during the 48 weeks of the study period.

## TABLE 28

## RECIRCULATION TANK EXPERIMENTAL PROGRAM
## SAMPLING SCHEDULE
## FOR ALL 8 TANKS

| Date | Week | Minerals | Metals | Asbestos |
|---|---|---|---|---|
| April 15, 1981 | 0 | X | X | X |
| April 22, 1981 | 1 | X | X | - |
| April 29, 1981 | 2 | X | X | - |
| May 6, 1981 | 3 | X | X | - |
| May 13, 1981 | 4 | X | X | - |
| May 20, 1981 | 5 | X | X | - |
| May 27, 1981 | 6 | X | X | - |
| June 3, 1981 | 7 | X | X | - |
| June 10, 1981 | 8 | X | X | - |
| June 17, 1981 | 9 | X | X | - |
| June 24, 1981 | 10 | X | X | - |
| July 1, 1981 | 11 | x | X | - |
| July 8, 1981 | 12 | X | X | - |
| August 5, 1981 | 16 | X | X | - |
| September 2, 1981 | 20 | X | X | - |
| September 30, 1981 | 24 | X | X | X |
| October 28, 1981 | 28 | X | X | - |
| November 25, 1981 | 32 | X | X | - |
| January 20, 1982 | 40 | X | X | - |
| March 17, 1982 | 48 | X | X | X |

## TABLE 29

## RECIRCULATION TANKS - CORRELATION OF RESULTS

| (1) Tank | (2) Total Coupon Exposure Time (coupon-weeks) | (3) Average Flow (gpm) | (4) Product (no units) |
|---|---|---|---|
| 1 | 120 | 2.31 | 277 |
| 2 | 120 | 2.53 | 304 |
| 3 | 96 | 2.77 | 265 |
| 4 | 96 | 2.66 | 255 |
| 5 | 96 | 2.70 | 259 |
| 6 | 96 | 2.56 | 246 |
| 7 | 96 | 2.64 | 253 |
| 8 | 96 | 2.66 | 255 |

As can be seen in Table 29, the recirculation flow rates in tanks 1 and 2 were slightly lower than those in tanks 3 through 8. This is due to the fact that four test coupons were installed in the test racks for tanks 1 and 2, requiring slightly longer piping and a longer test rack; thus, headlosses in the recirculation lines of tanks 1 and 2 were slightly higher and resulted in slightly reduced pumping rates.

The last column in Table 29 presents the product of columns 2 and 3, a representation of exposure. This product is a means of incorporating into a single measure, the effects of coupon exposure and flow rate past the coupons. As can be seen by the data shown in column four, variation from one tank to another in terms of total coupon exposure time and average flow rate was quite low. The highest number shown (304) is only 24 percent higher than the lowest number shown (246). Thus, differences from one tank to another would be minimally affected by differences in either coupon exposure time or flow rate.

Figures in the remainder of this section demonstrate that most water quality constituents leveled off after a certain period of time (normally approximately twenty weeks). Thus, any difference in exposure time or flow rate would not greatly influence the conclusions drawn herein.

## Control (Tanks 1 and 2)

Tanks 1 and 2 were utilized to determine the effects of exposure of Cedar and Tolt water, respectively, to A/C pipe coupons with no corrosion control chemicals added. The water quality parameters; pH, calcium, silica, alkalinity, and total hardness are shown with time in Figures 11 through 15 for tanks 1 and 2.

Constant pH was not maintained in tanks 1 and 2; rather, it was allowed to change with time during the study. As Figure 11 demonstrates, Cedar River water (tank 1) initially showed a pH of approximately 7.4. The initial pH of Tolt River (tank 2) was approximately 6.0. During the first six to eight weeks of the study, the pH of Cedar River water dropped to a value of approximately 7.0 while the pH of the Tolt River water rose to a similar figure. From that point forward and for the remainder of the study, the pH in the two tanks was usually within 0.1 to 0.2 units. The initial drop in the pH of the Cedar River water remains unexplained. However, the pH in both tanks did show a general increase for the remainder of the study, which would be expected due to the degradation of A/C pipe.

Figure 12 shows that the initial calcium concentration was 2 to 4 mg/L in Tolt water versus approximately 7 mg/L for Cedar River water. Analytical methods were refined during the first several weeks of sampling Tolt water due to the extremely low mineral content of the water and the resultant, highly sensitive, ion balance. Thus, the data shown for the first few weeks of testing are less reliable than later data. For the first 24 weeks of the study program, calcium concentrations for both tanks increased at similar rates. A total increase of 4 mg/L calcium in 24 weeks was observed in both tanks. In the twenty-fourth through the forty-eighth week of the program, calcium concentrations remained relatively constant at 7 mg/L for the Tolt system and approximately 11 mg/L for the Cedar system. It is interesting to note that distribution system results indicated an increase of calcium concentration in the distribution system of between 1 and 2 mg/L with a detention time of less than 24 hours. The reduced rate

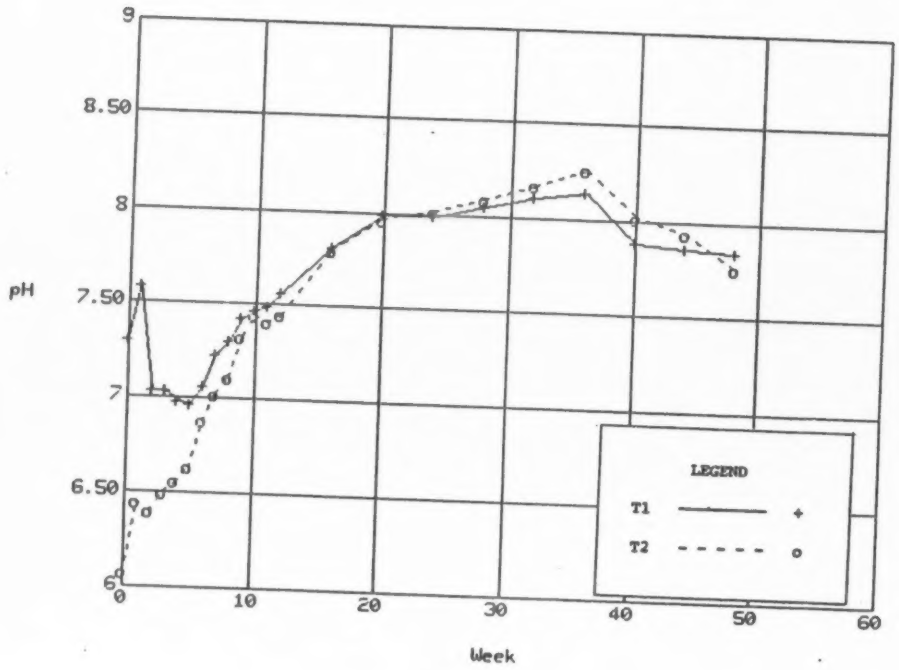


FIGURE 11
pH VERSUS TIME FOR TANKS 1 AND 2

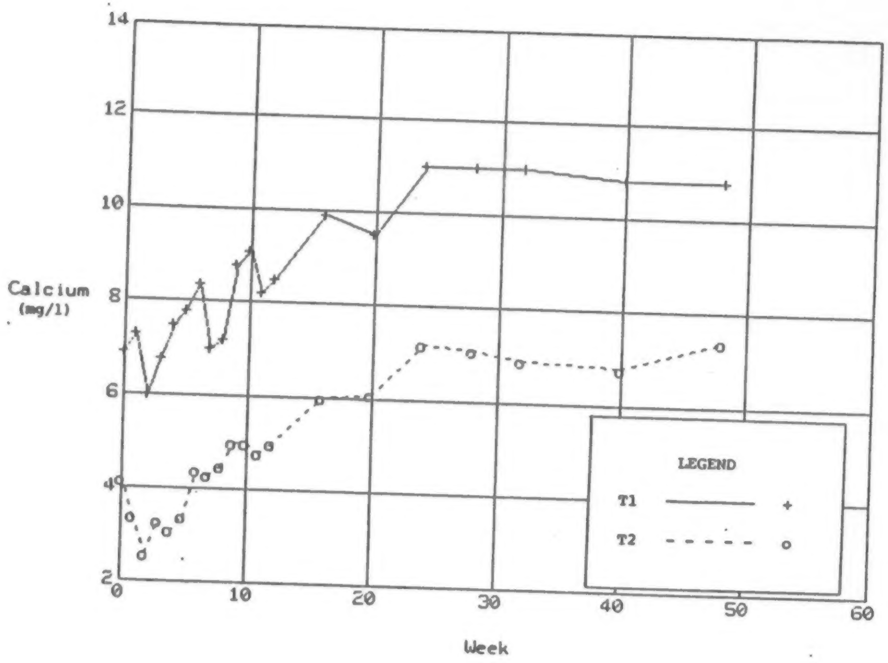


FIGURE 12
CALCIUM CONCENTRATION VERSUS TIME FOR TANKS 1 AND 2

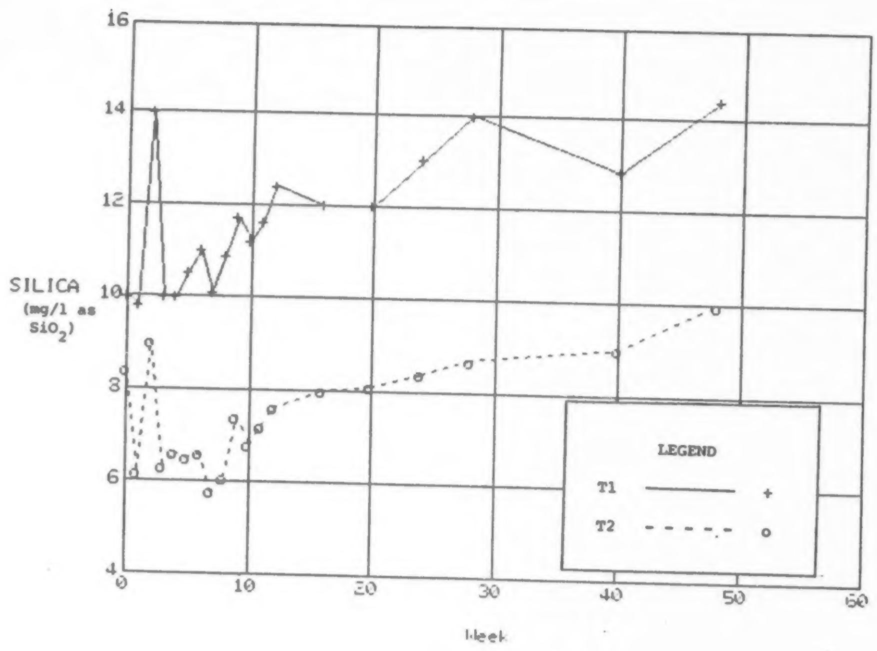


FIGURE 13
SILICA CONCENTRATION VERSUS TIME FOR TANKS 1 AND 2

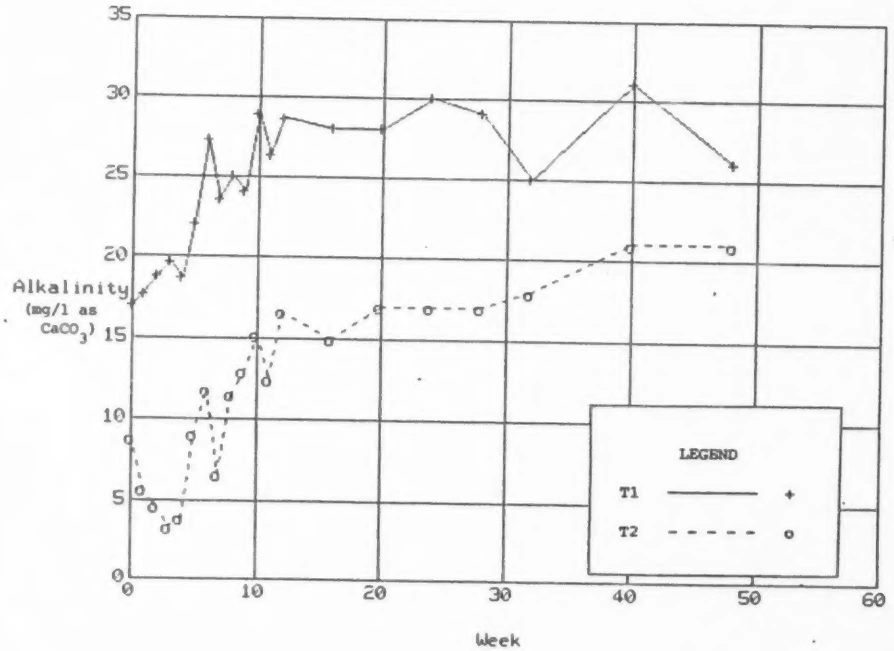


FIGURE 14
ALKALINITY VERSUS TIME FOR TANKS 1 AND 2

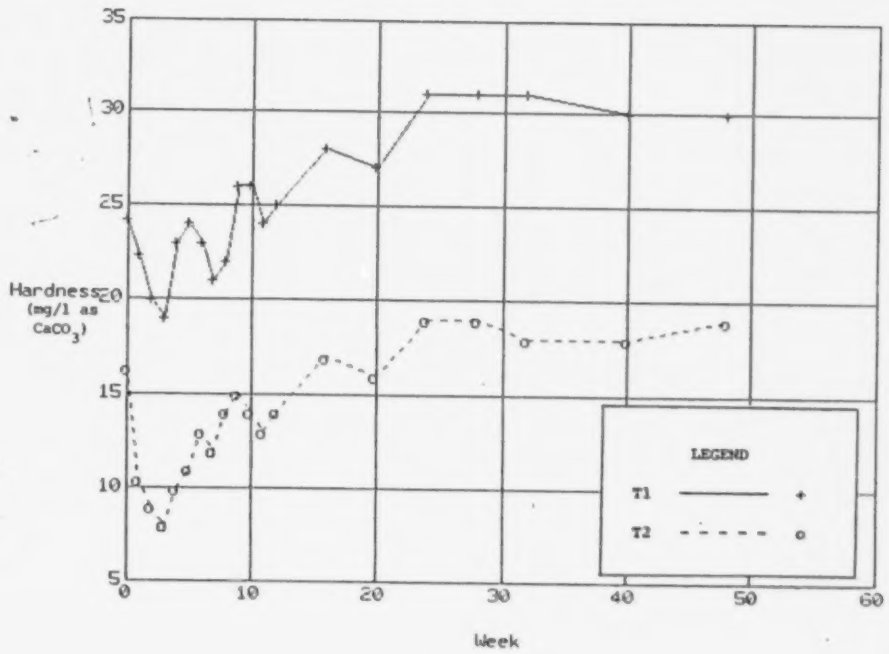


FIGURE 15
HARDNESS VERSUS TIME FOR TANKS 1 AND 2

of calcium increase in the recirculation tanks is most likely due to the small surface area of the coupons used relative to the amount of water flow.

Silica levels in the two tanks increase gradually across the entire 48 weeks of the study. For the Cedar system, the silica concentration rose in an almost linear fashion, from approximately 10 mg/L to approximately 14 mg/L. In the Tolt system, silica levels rose from approximately 6 mg/L to approximately 10 mg/L. data are shown in Figure 13.

Alkalinity in the two tanks increased for approximately the first 12 weeks of the study and then began to level off. This is shown in Figure 14. In both tanks, the observed increase over the course of the study was approximately 15 mg/L of alkalinity expressed as $CaCO_3$.

Total hardness (expressed as $CaCO_3$) is closely tied to calcium concentration and exhibited similar increases as previously described for calcium.

The overall conclusion to be drawn from Figures 11 through 15 is that the corrosion rates due to exposure of A/C test coupons to both Cedar and Tolt River water were similar with regard to calcium, silica, alkalinity and hardness when the pH was not maintained constant. Some differences are observed with regard to pH but, after a relatively short period of time, similar pH values are reached and remain closely aligned from that point forward. Calcium, silica, alkalinity, and hardness leveled off eventually for both tanks, but at different concentrations.

### Langelier Index Adjustment (Tanks 3 and 4)

Tank 3 was used to model those conditions (pH 8.0) which would exist in Bellevue's distribution system after adoption of the Seattle Corrosion Control Program. Tank 4, through addition of additional soda-ash and lime, maintained a pH of 9.0 and a slightly less negative Langelier Index (-0.2 as opposed to -1.3 in tank 3). Figures 16 through 19 show calcium, silica, alkalinity and hardness values plotted versus time for Tanks 2, 3, and 4. Tank 2 is included in these figures for comparison purposes since it represents baseline conditions of Tolt water with no corrosion control measures.

Figure 16 shows that calcium pickup from the A/C test coupons is reduced from approximately 5 mg/L in the control tank (tank 2) to approximately 2.5 mg/L in tank 3. The higher pH maintained in tank 4 appears to have no significant additional effect on limiting calcium pickup. At least in terms of calcium, Figure 16 indicates that corrosion rates in Bellevue's system may be reduced through adoption of the Seattle Corrosion Control Program. Figure 16 also suggests that further adjustments to pH through addition of lime or soda ash would yield no significant additional benefits.

Silica increases in tanks 3 and 4 were also reduced below those observed in tank 2. This is demonstrated in Figure 17. In the control tank (Tank 2), silica increased from a value of approximately 6 mg/L to approximately 10 mg/L over the 48 weeks of the study. In Tanks 3 and 4, silica levels, over a similar period, rose from approximately 6 mg/L to approximately 8 mg/L. Thus, it would appear that silica increases have also been inhibited through the addition of lime and soda ash, and adjustment of the Langelier Index. However, tank 4 exhibits no clear advantage over those conditions observed in

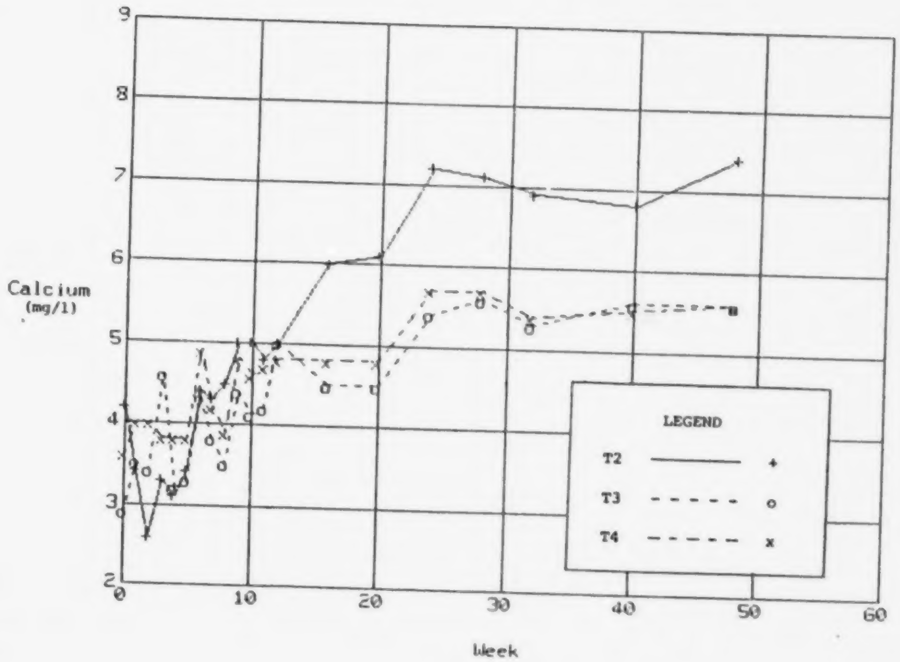


FIGURE 16
CALCIUM CONCENSTATION VERSUS TIME FOR TANKS 2, 3 AND 4

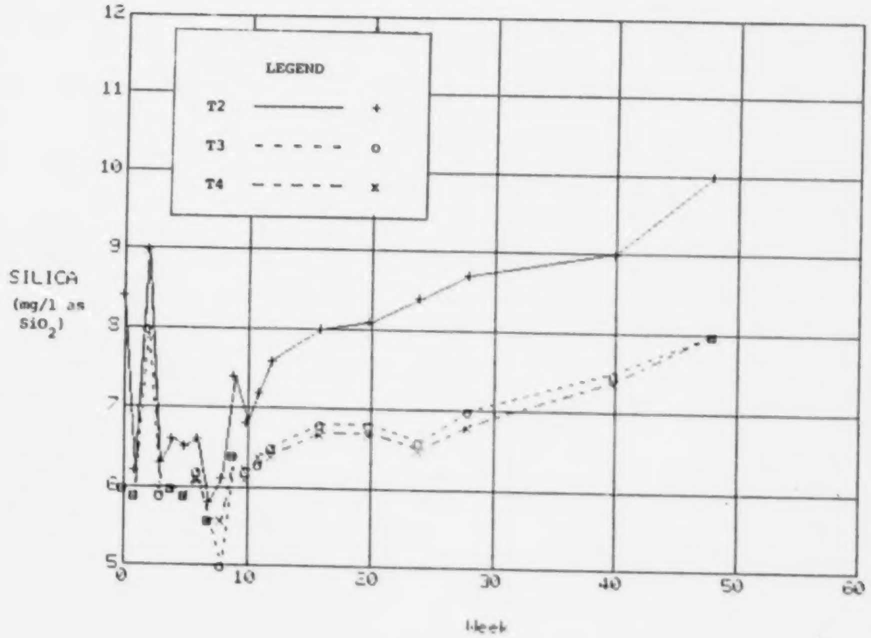


FIGURE 17
SILICA CONCENTRATION VERSUS TIME FOR TANKS 2, 3 AND 4

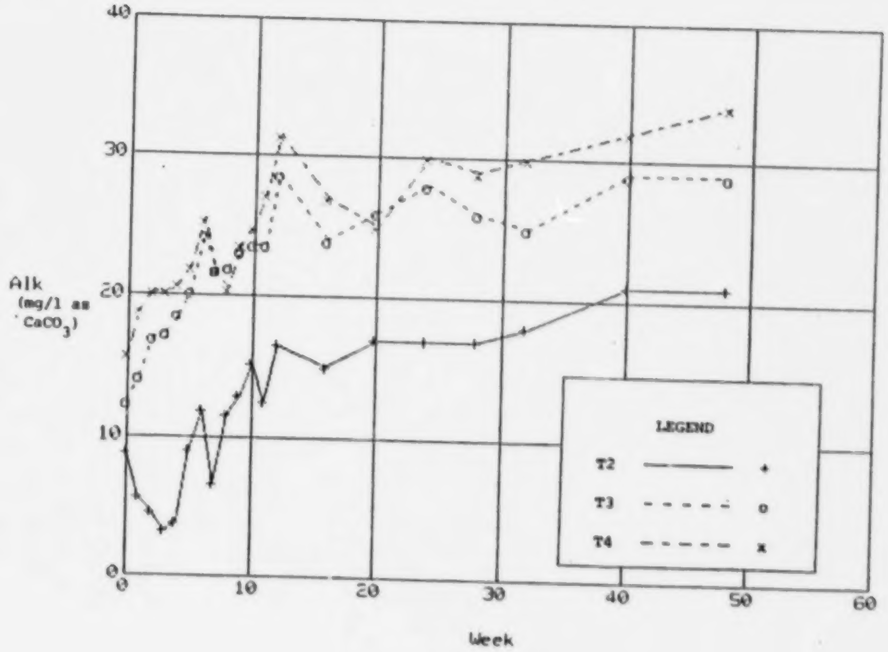


FIGURE 18
ALKALINITY VERSUS TIME FOR TANKS 2, 3 AND 4

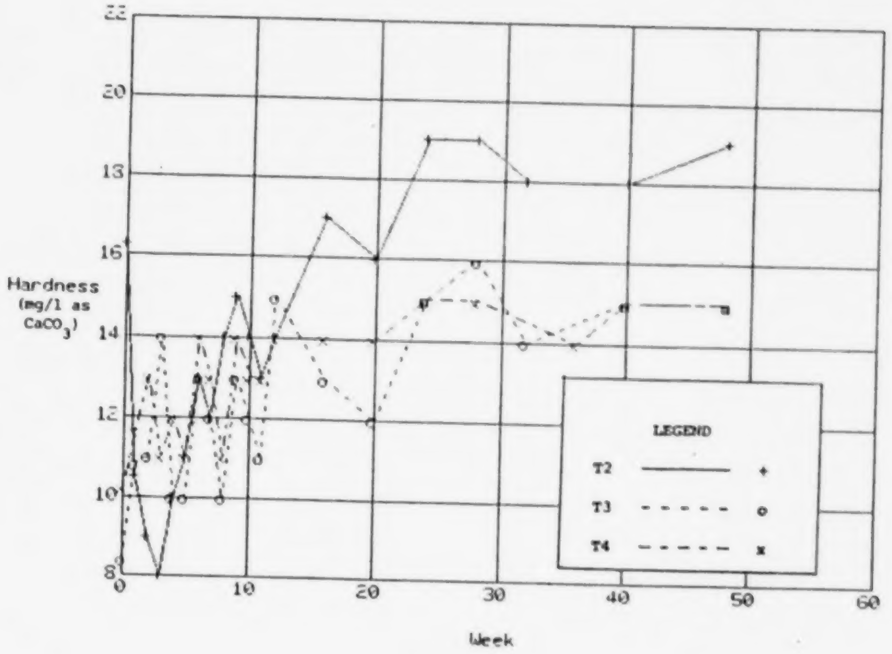


FIGURE 19
HARDNESS VERSUS TIME FOR TANKS 2, 3 AND 4

tank 3 and further adjustment of the Langelier Index, beyond that accomplished in tank 3, does not yield significant benefits.

Langelier Index adjustment appears to have little effect on the alkalinity increase rate with exposure to A/C test coupons. Figure 18 demonstrates that, while the initial alkalinity concentration for tanks 3 and 4 are somewhat higher than tank 2 (due to the addition of soda ash), the rate of increase and the net increase over the 48 week study period are virtually the same for all three tanks. As noted previously, the alkalinity increase observed in each of the tanks was affected by those chemicals used to maintain pH, namely caustic soda (NaOH) and hydrochloric acid (HCl). The alkalinity effects of those chemical additions have not been separated out in the alkalinity plots shown in this section.

Figure 19 demonstrates that total hardness for tanks 2, 3, and 4 followed a very similar pattern to the calcium pickup previously shown in Figure 16.

## Zinc Corrosion Control Strategies (Tanks 5 and 6)

Tanks 5 and 6 investigated the effectiveness of zinc chloride addition (in combination with adoption of the Seattle Corrosion Control Program) on mitigation of corrosion of A/C test coupons. Tank 5 investigated a lower dosage of zinc chloride (0.3 mg/L as zinc) at an increased pH (8.5) and tank 6 investigated a higher dosage of zinc chloride (0.6 mg/L as zinc) and lower pH (8.0).

Figures 20 through 23 illustrate the effects of zinc chloride addition to tanks 5 and 6 on calcium, silica, alkalinity and hardness increases. Figure 20 indicates that calcium levels in both tanks 5 and 6 increased by approximately 1.5 mg/L during the study. This is opposed to an observed increase of approximately 5 mg/L in the control tank (tank 2), an observed increase of approximately 2 mg/L in the Langelier Index adjustment tanks (tanks 3 and 4), and an observed increase in calcium concentrations of 2.5 to 3.0 mg/L in the sodium metasilicate and iron addition control tanks (tanks 7 and 8). The increases in calcium for tanks 5 and 6 (shown in Figure 20) were the lowest observed for any of the tanks, and indicate that some form of corrosion inhibition is being achieved. The release of calcium from the test coupons to the recirculated water in tanks 5 and 6 is approximately one-third that in the control tank.

Figure 21 also shows that only a slight increase in silica concentrations was observed with time in tanks 5 and 6. This offers further proof that some corrosion inhibition is being achieved in these tanks.

The alkalinity relationship shown in Figures 22 shows little effect of zinc chloride addition on alkalinity, and the hardness vs. time relationship shown in Figure 23 is very similar to that previously presented for calcium in Figure 20.

Figure 24 indicates the level of soluble zinc maintained in the two zinc addition tanks and the naturally occurring zinc levels in the control tank (Tank 2). This figure illustrates that soluble zinc levels at the two different pH values (8.5 in tank 5 and 8.0 in tank 6) were fairly close despite the fact that REDEQL computer modelling efforts indicated that substantially different solubilities would result (approximately 0.2 mg/L was predicted at a pH of 8.5 and 0.5 mg/L was predicted at pH 8.0). During the first

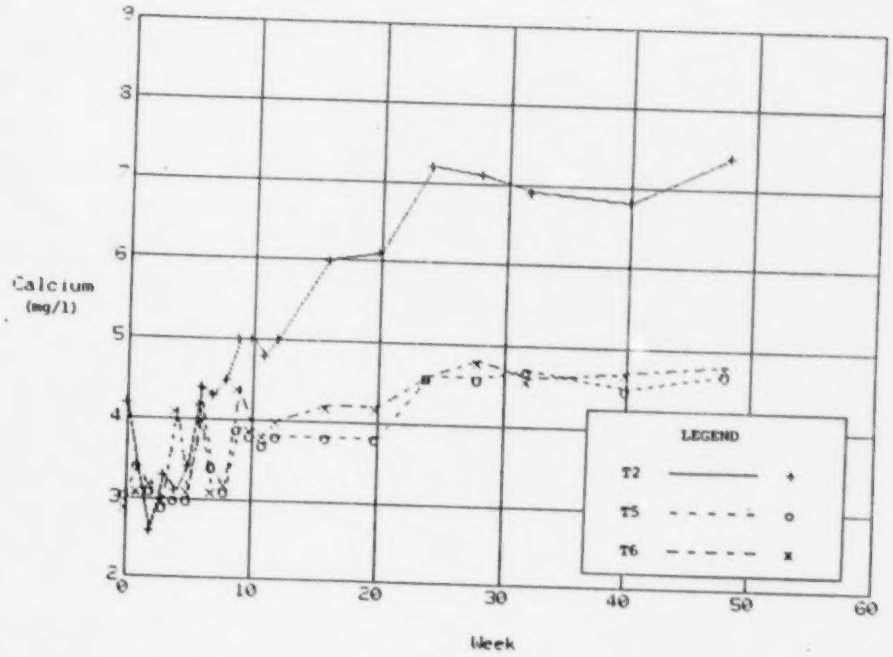


FIGURE 20
CALCIUM CONCENTRATION VERSUS TIME FOR TANKS 2, 5 AND 6

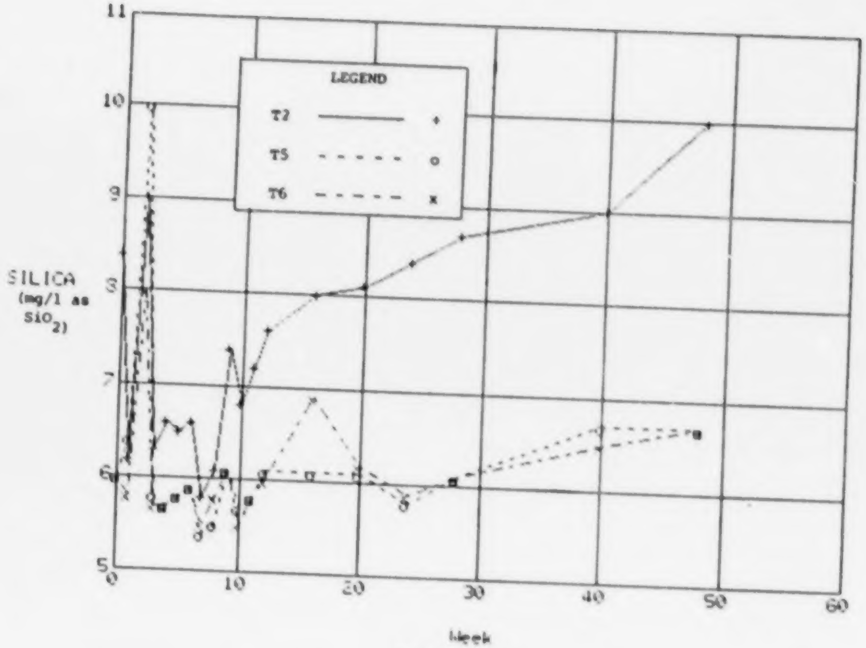


FIGURE 21
SILICA CONCENTRATION VERSUS TIME FOR TANKS 2, 5 AND 6

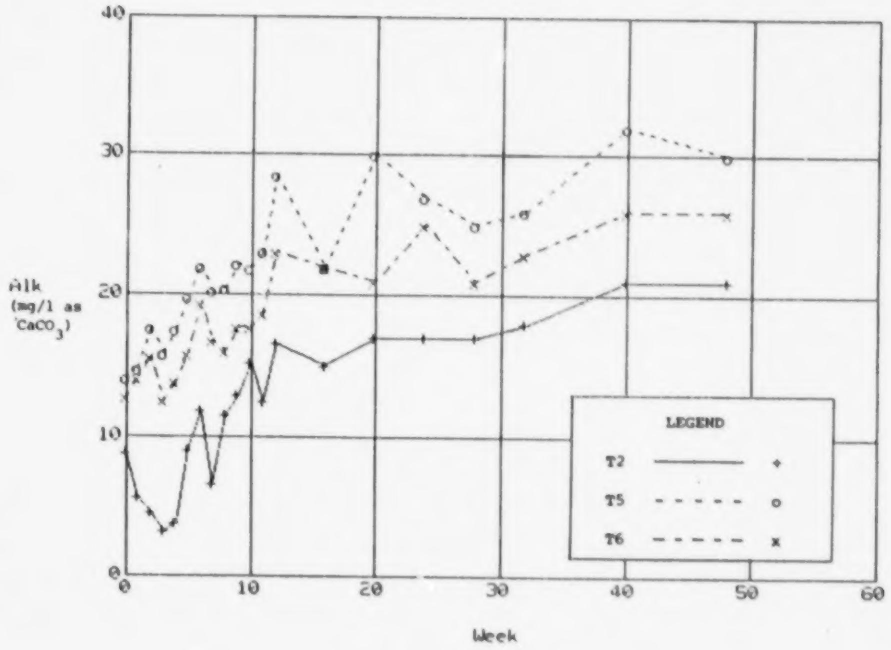


FIGURE 22
ALKALINITY VERSUS TIME FOR TANKS 2, 5 AND 6

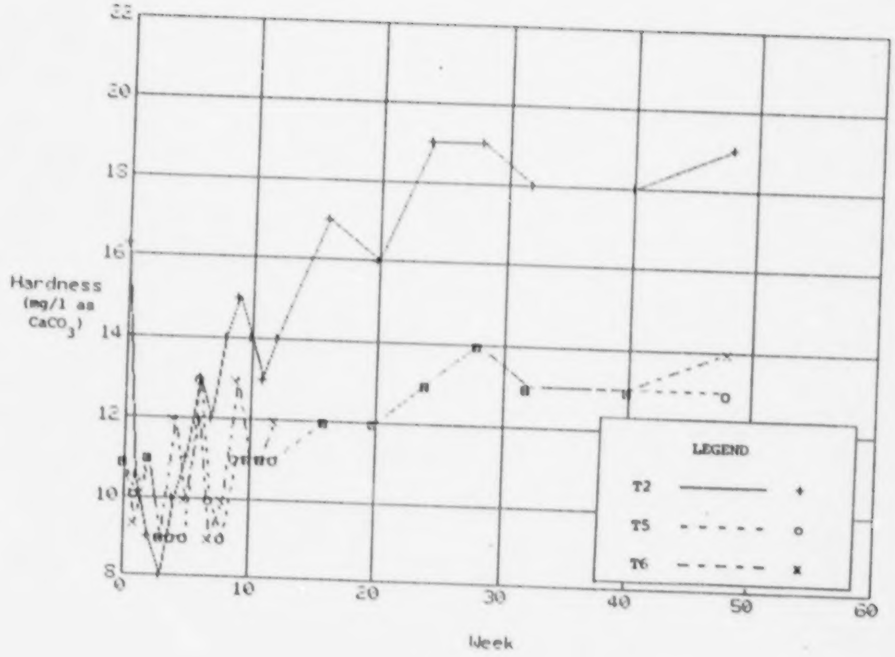


FIGURE 23
HARDNESS VERSUS TIME FOR TANKS 2, 5 AND 6

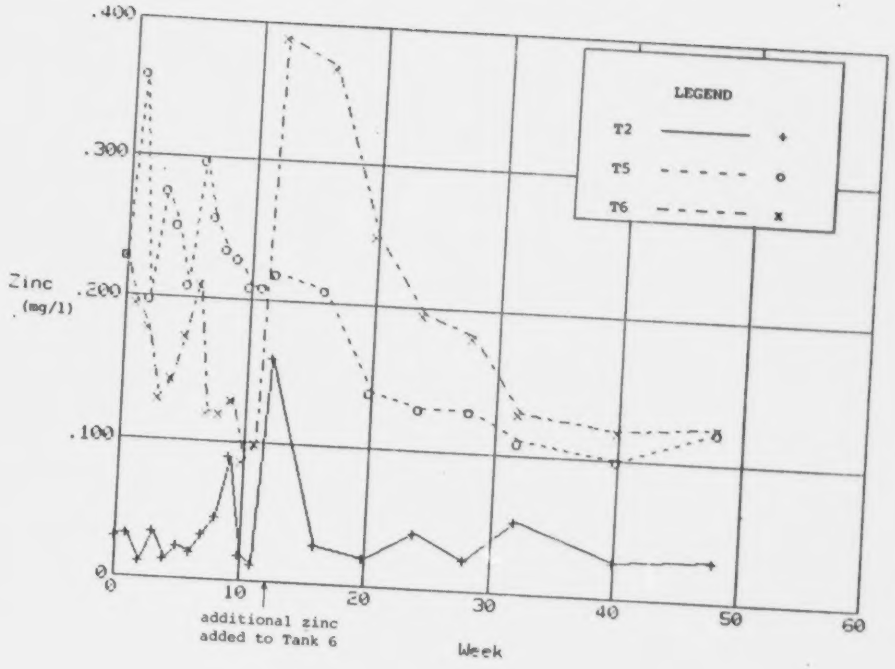


FIGURE 24
ZINC CONCENTRATION VERSUS TIME FOR TANKS 2, 5 AND 6

12 weeks of this study it was noted that the zinc concentration maintained in tank 6 was somewhat lower than that maintained in tank 5, despite the fact that a higher dosage of zinc had been applied to tank 6 (0.6 mg/L vs. 0.3 mg/L in tank 5). For this reason, additional zinc was added in week twelve to bring the soluble zinc level back up to 0.6 mg/L and to then observe the decrease in concentration of soluble zinc with time. The zinc concentration in tank 6 decreased from the added 0.6 mg/L to approximately 0.1 mg/L over the remainder of the study. Interestingly, the soluble zinc concentration in tank 5 also subsided to approximately the same level. The implications of this behavior are not fully understood at this time. However, it would appear that the solubility concentrations of zinc predicted by REDEQL modelling are misleading. This may be due to not considering all possible solids during the computer runs, error in perdicting solely on the basis of equilibrium without considering kinetics, or surface reactions which effectively remove zinc from the bulk solution.

## Iron and Silicate Control Strategy (Tanks 7 and 8)

Figures 25 through 29 show the results of testing using sodium metasilicate and ferric chloride for corrosion inhibition in tanks 7 and 8, respectively. Figure 25 indicates that the calcium increase in both tanks 7 and 8 was reduced from the control tank level of 5 mg/L to approximately 2.5 to 3 mg/L. Results correspond to tank 3, so it would appear that the addition of ferric chloride or sodium metasilicate offers no real advantage to that corrosion protection already afforded by the Seattle Corrosion Control Program at least in terms of calcium pickup.

Figures 26 and 28 show that some reduction of silica and hardness increases were achieved in tank 8 versus tank 2, but that less protection is afforded than in the zinc tanks (tanks 5 and 6, Figures 21 and 23).

Figure 29 indicates the residual iron concentration maintained in tank 8 and in the control tank (tank 2) during the study period; approximately 0.2 mg/L as iron (III) was added to tank 8. Thus, in combination with the raw water level of iron of approximately 0.1 mg/L, the initial concentrations in tank 8 was approximately 0.3 mg/L. Figure 29 indicates that the soluble iron level did not drop significantly during the 48 week test program. Iron concentration did appear to decrease by approximately 0.1 mg/L over the first 20 weeks; however, after that, levels appeared to be more erratic. Upon removal, the A/C test coupons did exhibit a reddish-brown color that would be typical of an iron precipitate on the surface of the coupon.

## Asbestos Analyses

Table 30 presents the data obtained for chyrostile fiber counts in the eight recirculation tank experiments. Sampling was described in Section 5. At time zero, fiber counts ranged from 3.1 MFL in tank 8 to 24.6 MFL in tank 2. This variation of approximately one order of magnitude is possibly due to statistical variation of the measurement technique or to variations in tank fiber content due to dust or clumping of fibers in the original sample.

Results at weeks 24 and 48 indicate that fiber levels increased in each of the tanks. However, those results shown for tanks 5, 6 and 7 indicate that the best inhibition of

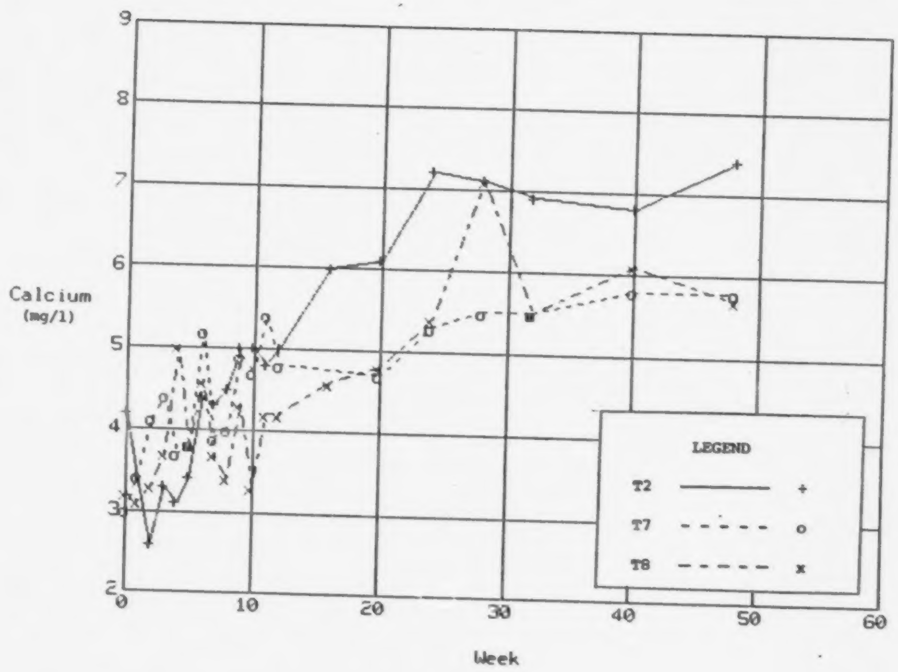


FIGURE 25
CALCIUM CONCENTRATION VERSUS TIME FOR TANKS 2, 7 AND 8

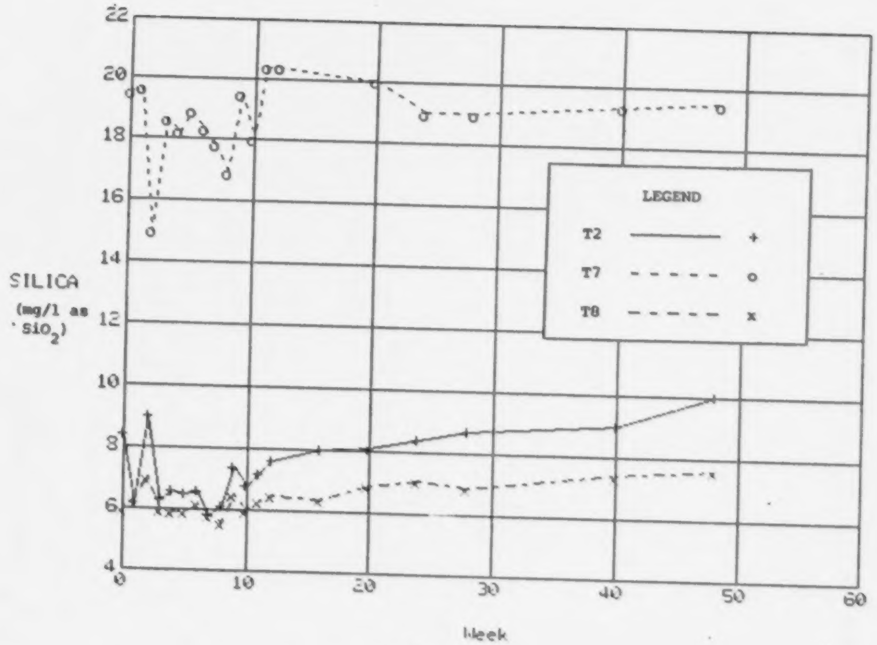


FIGURE 26
SILICA CONCENTRATION VERSUS TIME FOR TANKS 2, 7 AND 8

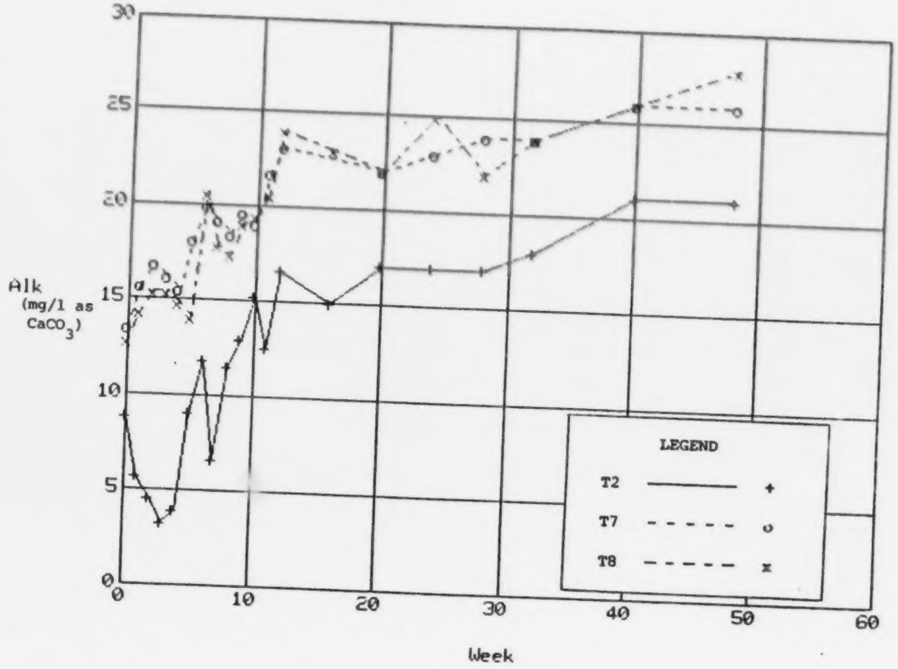


FIGURE 27
ALKALINITY VERSUS TIME FOR TANKS 2, 7 AND 8

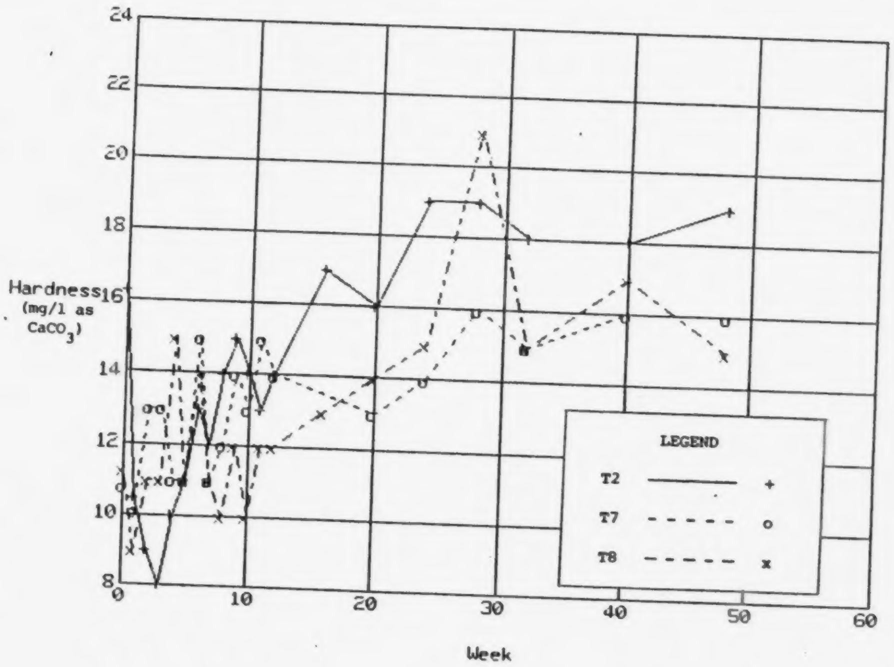


FIGURE 28
HARDNESS VERSUS TIME FOR TANKS 2, 7 AND 8

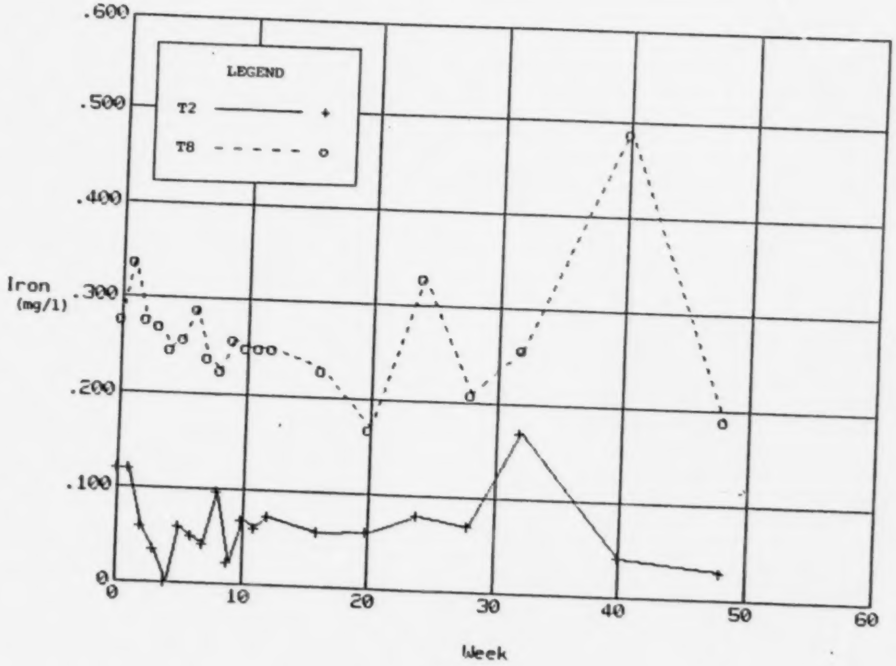


FIGURE 29
IRON CONCENTRATION VERSUS TIME FOR TANKS 2 AND 8

## TABLE 30

## CHRYSOTILE CONCENTRATIONS OVER TIME IN THE EIGHT TANKS

| Tank | Week 0 (MFL) | Week 24 (MFL) | Week 48 (MFL) |
|---|---|---|---|
| 1 | 5.1 | 50.92 | 60.88 |
| 2 | 24.6 | 54.46 | 69.26 |
| 3 | 10.7 | 255.89 | 82.1 |
| 4 | 17.3 | 51.87 | 166.4 |
| 5 | 9.7 | 12.69 | 23.7 |
| 6 | 8.4 | 40.68 | 34.88 |
| 7 | 12.5 | 34.49 | 39.7 |
| 8 | 3.1 | 76.11 | 169.6 |

fiber release was accomplished in these tanks. This was true at both the 24 week and the 48 week sampling period.

Data contained in Table 30 indicate that the zinc corrosion control strategies (tanks 5 and 6) show the most potential for corrosion inhibition from the point of view of asbestos fiber release. Control in tank 5, specifically, performed most effectively at limiting fiber release.

Table 31 includes amphibole data for samples drawn from the tanks during the study program. Data contained in this table indicate that amphibole fibers were only sporadically detected in samples drawn from the recirculation tanks. This result is reasonable since amphibole is not used in manufacturing asbestos-cement pipe.

## Physical Testing of A/C Test Coupons

Test coupons from each of the tanks were tested for weight loss, change in hardness, and calcium loss.

## Weight Loss Data for A/C Test Coupons

Table 32 presents weight loss data obtained for the coupons used in tanks 1 through 8. Data for tanks 1 through 4 indicate that some weight loss occurred during the course of these experiments. Data for tanks 5 through 8 indicate that weight gain was observed for the zinc, iron and silicate tanks. While these numbers should not be interpreted as absolute values for the weight of any material precipitated in the tanks, they do have value in assessing the relative merits of the various corrosion control strategies tested. Some precipitation of material occurred in tanks 5 through 8 but not in tanks 1 through 4. The effectiveness coating afforded by this precipitation may not be characterized or assessed for corrosion protection strictly on this data.

## Hardness Testing of A/C Coupons

As described in Section 5, each of the test coupons used in the eight recirculation, corrosion control experiments was tested for hardness using the Shore "D" and the Rockwell "L" scale hardness test procedures. Each of the 18 test coupons used in the experiments was tested according to these procedures. Table 33 presents the results of hardness testing of these coupons. All of the samples exhibited some softening when compared to new pipe sample test results. However, of the six corrosion control strategy tanks (tanks 3 through 8), the zinc strategies again appeared to result in the least softening of pipe coupons, although the differences were slight.

Data shown in Table 33 for tanks 1 and 2 provide some indication of the time-frame over which softening of the pipe coupon occurs.

Again, the data shown in Table 33 are insufficient, when viewed alone, to support the assumption that zinc control strategies work best at minimizing corrosion of A/C pipe with Tolt River water. However, when viewed in conjunction with the other data

## TABLE 31

## AMPHIBOLE CONCENTRATIONS OVER TIME

| Tank | Week 0 (MFL) | Week 24 (MFL) | Week 48 (MFL) |
|---|---|---|---|
| 1 | ND | ND | ND |
| 2 | ND | ND | ND |
| 3 | ND | ND | 0.99 |
| 4 | ND | ND | ND |
| 5 | 0.5 | ND | ND |
| 6 | ND | ND | ND |
| 7 | ND | ND | ND |
| 8 | ND | ND | ND |

ND denotes "None Detected"

## TABLE 32

## WEIGHT CHANGES OBSERVED IN TANK COUPONS

| Coupon Tank | Weight Before No. | Weight After Test (gms) | Weight Change Test (gms) | Exposure (gms) | (Weeks) |
|---|---|---|---|---|---|
| 1 | T1-1 | 183.3 | 176.0 | -7.3 | 12 |
| | T1-2 | 178.9 | 175.6 | -3.3 | 24 |
| | T1-4 | 190.3 | 185.6 | -4.7 | 48 |
| 2 | T2-1 | 186.7 | 179.8 | -6.9 | 12 |
| | T2-2 | 193.5 | 186.1 | -7.4 | 24 |
| | T2-4 | 191.6 | 188.6 | -3.0 | 48 |
| 3 | T3-1 | 155.7 | 155.4 | -0.3 | 48 |
| | T3-2 | 185.9 | 186.6 | +0.7 | 48 |
| 4 | T4-1 | 162.0 | 158.0 | -4.0 | 48 |
| | T4-2 | 188.1 | 187.8 | -0.3 | 48 |
| 5 | T5-1 | 192.3 | 195.2 | +2.9 | 48 |
| | T5-2 | 166.6 | 170.1 | +3.5 | 48 |
| 6 | T6-1 | 199.0 | 201.4 | +2.4 | 48 |
| | T6-2 | 182.4 | 185.9 | +3.5 | 48 |
| 7 | T7-1 | 187.4 | 191.4 | +4.0 | 48 |
| | T7-2 | 191.7 | 196.4 | +4.7 | 48 |
| 8 | T8-1 | 183.6 | 185.5 | +1.9 | 48 |
| | T8-2 | 169.1 | 172.1 | +3.0 | 48 |

All coupons dried 8 - 12 hours at 70° C.

## TABLE 33

## HARDNESS TEST RESULTS FOR COUPONS TESTED IN RECIRCULATION TANK, CORROSION CONTROL EXPERIMENTS*

| Tank | Conditions | Coupon No. | Exposure Time (Weeks) | Shore "D" Hardness | Rockwell "L" Scale Hardness |
|---|---|---|---|---|---|
| 1 | Cedar Control | T1-1 | 12 | 88 | 102 |
| | | T1-2 | 24 | 88 | 97 |
| | | T1-3 | 36 | 80 | 98 |
| | | T1-4 | 48 | 84 | 93 |
| 2 | Tolt Control | T2-1 | 12 | 88 | 101 |
| | | T2-2 | 24 | 88 | 100 |
| | | T2-3 | 36 | 81 | 98 |
| | | T2-4 | 48 | 87 | 91 |
| 3 | Tolt; Seattle Corrosion Control Program (SCCP); pH = 8.0 | T3-1 | 48 | 85 | 89 |
| | | T3-2 | 48 | 82 | 93 |
| 4 | Tolt; SCCP; Add'l lime; pH = 9.0 | T4-1 | 48 | 85 | 87 |
| | | Tr-2 | 48 | 85 | 92 |
| 5 | Tlt; SCCP; 0.3 mg/L Zn; pH = 8.5 | T5-1 | 48 | 87 | 92 |
| | | T5-1 | 48 | 86 | 95 |
| 6 | Tolt; SCCP; 0.6 mg/L Zn; pH = 8.0 | T6-1 | 48 | 86 | 95 |
| | | T602 | 48 | 85 | 98 |
| 7 | Tolt; SCCP; 12.7 mg/L $SiO_2$ pH = 8.0 | T7-1 | 48 | 83 | 90 |
| | | T7-2 | 48 | 82 | 90 |
| 8 | Tolt; SCCP; 0.2 mg/L Fe; pH = 8.0 | T8-1 | 48 | 82 | 91 |
| | | T8-2 | 48 | 82 | 92 |

*All samples oven dried.

collected within this report, they would support the conclusion that the zinc corrosion control strategies outperform the other strategies tested.

### Calcium Loss Via Scanning Electron Microscope Analysis

In addition to the tests just described, all of the coupons from the control tanks, and one coupon each from the corrosion control strategy tanks were submitted to the EPA for testing by scanning electron microscopy. Tests were performed by the Toxicology and Microbiology Division of EPA, Cincinnati, using the x-ray analysis method of Millette (1983) using a scanning electron microscope. Thus, calcium loss measurements were obtained in millimeters and are shown in Table 34.

These data indicate that calcium loss, for those tanks other than the zinc corrosion control strategies, ranged from 0.21 to 0.36 mm for those coupons that had been exposed for 48 weeks. Similar measurements for coupons for tanks 5 and 6, indicate that calcium loss of 0.0 and 0.05 mm occurred respectively. Thus, on the basis of this additional testing, the conclusion is also drawn that the zinc corrosion control strategies tested worked best at limiting corrosion of A/C pipe and inhibiting the subsequent release of asbestos fibers.

## CONCLUSIONS

The following are conclusions based on the Phase IB results:

1. The zinc chloride corrosion control strategies tested in tanks 5 and 6 were most efficient at controlling the attack of A/C pipe by Tolt water. No substantial differentation was made between the low pH, high zinc dose tank (tank 6) and the high pH, low zinc dose tank (tank 5); both appeared to work well. This conclusion is based on water quality sampling during the Phase 1B testing program, asbestos fiber counts, coupon hardness tests, weight loss data and calcium loss measurements made via SEM. The conclusion that the zinc corrosion control strategies were most effective is relatively straightforward since each of the testing procedures employed indicate that the zinc tanks will out perform the other strategies tested.

2. If a single test strategy must be identified as most effective, then that strategy employed in tank 5 (Seattle Corrosion Control Program, zinc dose of 0.3 mg/L, pH of 8.5) would be recommended based on the lower asbestos fiber counts observed and the least calcium loss as determined by SEM analysis. However, it must also be noted that the differences between the performance of tanks 5 and 6 are slight. The final decision as to whether to adopt a low or high zinc dosage and a low or high pH must be based on further economic and other analyses of the alternatives available. In fact, the strategy ultimately chosen for Phase II was a higher zinc dose (0.6 mg/L) and no additional pH adjustment beyond that which Seattle instituted, principally to make controls simpler.

## TABLE 34

## SEM TESTING RESULTS*

| Tank | Measured Ca Loss After 48 Weeks Exposure (mm) |
|---|---|
| 1 | 0.21 |
| 2 | 0.27 |
| 3 | 0.36 |
| 4 | 0.25 |
| 5 | 0.0 |
| 6 | 0.05 |
| 7 | 0.35 |
| 8 | 0.25 |

---

* All tests performed by USEPA

# SECTION 8

# PHASE II: FIELD TEST

## INTRODUCTION

The field test was designed to measure the effectiveness of zinc chloride, which was found in the Phase IB recirculation test to give the best corrosion protection for A/C pipe. Field testing began in March, 1983 just after the City of Seattle completed the startup of their corrosion control program, which included pH and alkalinity adjustment of their Tolt River water supply. Thus the conditions were very similar to tank 6 of the recirculation test discussed in Section 7.

## APPROACH AND ORGANIZATION

In preparing for the field test, choosing the best test area was the most important task. In addition to requiring convenient locations for sampling at inlets, outlets and deadends, the test site had to meet criteria for detention time, proper water supply, and various mechanical concerns. After the test site was chosen, the equipment was installed and the proper zinc dose set. At the same time the potential impacts of the zinc addition on water users were considered to avoid any adverse side effects of the field test. The following paragraphs discuss these topics in detail.

### Site Selection

The test area chosen had to meet six basic criteria:

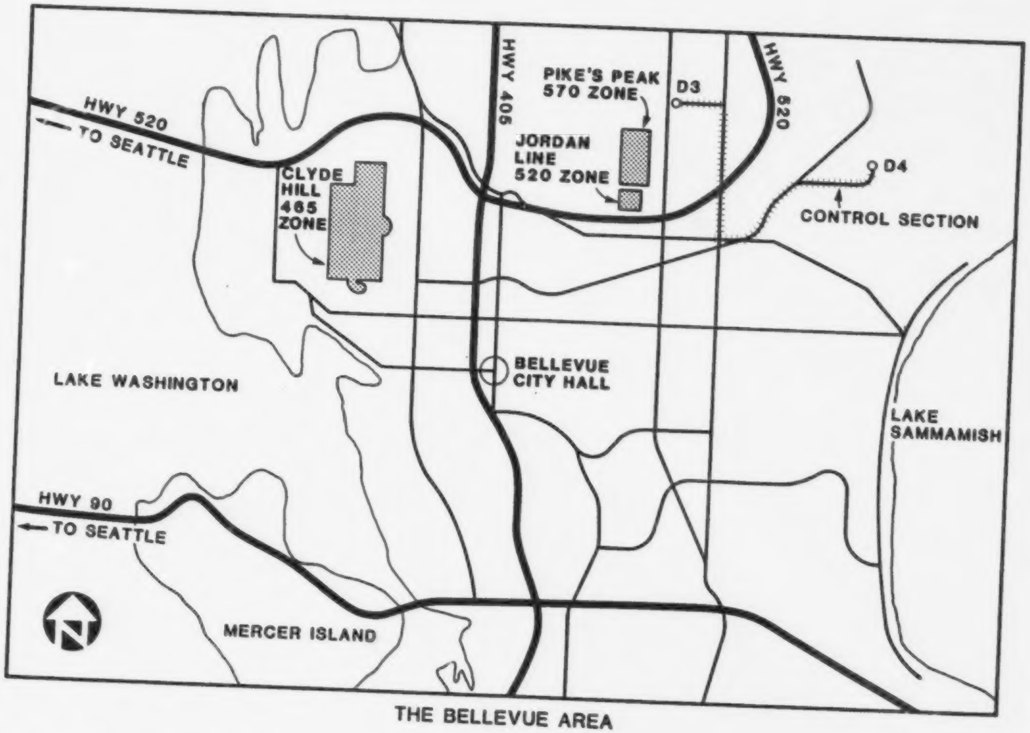
- The site must receive Tolt water which is more aggressive than Cedar water, having a lower pH and a lower alkalinity.
- The area must be isolated to avoid affecting the control area.
- The area must be small enough to minimize chemical costs.
- The detention time for the test area should be approximately 15 to 20 hours between the chemical addition and the final sampling point in order to match the detention times used in Phase IA.
- A control area with the same water supply and similar detention time must be available.

- The site should have a structure available for housing the chemical feed system to protect it from the elements. It must also have a flow metering system which can be used to pace the chemical feed into the water supply lines.

Four candidate test sites meeting some or all of the criteria were found; they are diagramed on a map in Figure 30. Of these four, Clyde Hill was chosen. The other areas under consideration were the Pike's Peak 570 Zone, Jordan Line 520 Zone, and finally the 520 Blue Zone (northern portion) which covers the eastern third of Bellevue in Figure 30. The 520 Blue Zone was a difficult pipe network to isolate, and was soon dropped from further consideration. Another problem with this zone was the large flow through the area and the possibility that water could come from the Redmond system, which would cause jurisdictional problems when adding zinc. In contrast, Clyde Hill was an isolated zone served by a single pump station, which made it easy for chemical addition and kept it separate from the control area. The existing pump station provided power and the necessary protective structures for the chemical feed and chemical storage required for the project. By comparison, the Pike's Peak 570 and the Jordan Line 520 Zones both lacked any sort of structure or available power.

Once the test site was chosen, location names were assigned to all of the sampling points. The basic elements of the system were sampling points at the influent, effluent, and one point just after chemical addition to test the zinc dosage. Other important sampling points were dead-ends, where particulates could accumulate, and sewers draining the area to indicate how much zinc was actually leaving the system. A map showing the location of these sampling points and the Clyde Hill pipe network is shown in Figure 31. The prefix "CH" was applied to all of the points on the system to stand for "Clyde Hill". The two sewage sampling points were called S1 and S2, respectively. CH1 (Figure 32) was located at the Clyde Hill Pump Station just before the chemical addition point. CH1A was a fire hydrant several hundred yards downstsream from the chemical injection point which allowed the zinc dose to be verified. CH2 was at the end of the system, and represented water after 16 to 18 hours detention time, according to network modeling. The sampler installed there was a continuous flow device identical to the one installed at D4 (Figure 6). An alternate sampling point for CH2 was considered on the north side of the Clyde Hill system. However, it did not offer a sufficiently long detention time and was rejected. CH3 and CH4 were dead-ends on the Clyde Hill system, serving as checks for any buildup of particulate zinc. CH3 was a stand pipe near the pump station which is active only in the evenings. CH4 was an actual dead-end pipe on the west side of the distribution system.

The control area chosen was the same as that used to document the existing conditions in Phase IA (Section 6) for Tolt water in Bellevue; it is located in the northeast section of the City of Bellevue. The original sampling location designations, D3 and D4, were kept for the field test. D3 (Figure 5) is at the entrance to the system, located directly off the East Side Supply Line just before water entered the A/C pipe network of the control area. D4 (Figure 6) was located at the end of the pipe run, where modeling showed that the detention time to be 15 to 25 hours.


HWY 520
TO SEATTLE
CLYDE HILL 465 ZONE
HWY 405
PIKE'S PEAK 570 ZONE
D3
JORDAN LINE 520 ZONE
HWY 520
D4
CONTROL SECTION
BELLEVUE CITY HALL
LAKE WASHINGTON
LAKE SAMMAMISH
HWY 90
TO SEATTLE
MERCER ISLAND
N

THE BELLEVUE AREA

FIGURE 30

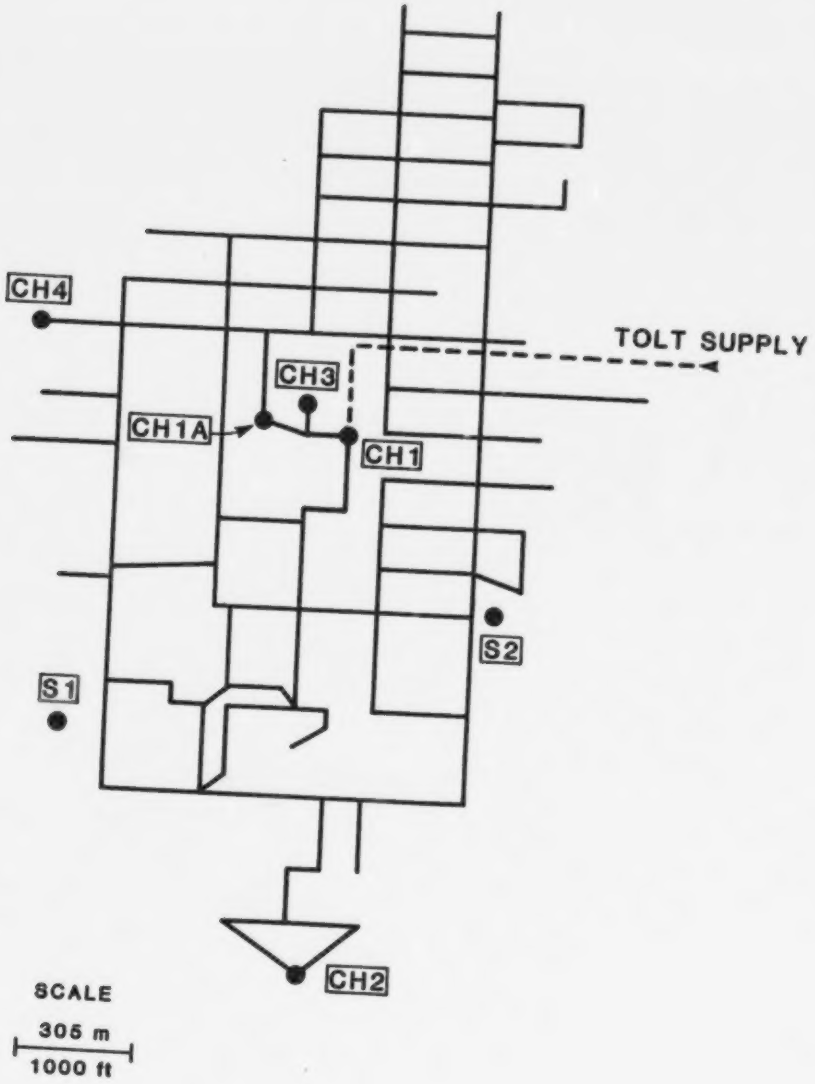
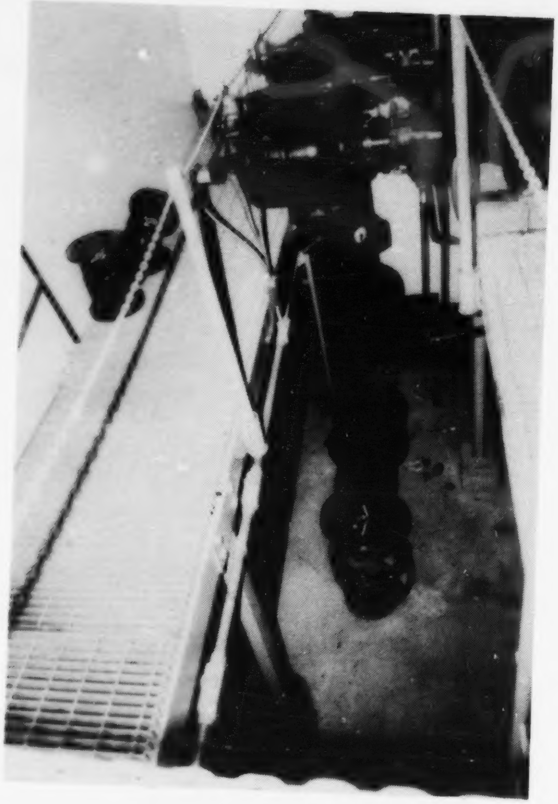

CH4
TOLT SUPPLY
CH3
CH1A
CH1
S2
S1
CH2
SCALE
305 m
1000 ft

FIGURE 31

CLYDE HILL 465 ZONE
PIPE NETWORK



SAMPLE STATION CH1: THE INLET TO THE CLYDE HILL SYSTEM
FIGURE 32

## Sampling Program

The sampling schedule is shown in Table 35. General mineral, zinc, and asbestos samples were taken monthly at the inlet and outlet of both the test and the control section. The water quality parameters included under general minerals are listed in Table 35. Particulate and total zinc samples were taken at the dead-ends of the Clyde Hill (CH3 and CH4) system on a quarterly basis.

## Zinc Dose

The zinc chloride dose was chosen to be 0.6 mg/L as zinc, with the pH and alkalinity conditions present in the Tolt water supply as supplied by Seattle to the City of Bellevue. The Tolt pH during the study was between 7.9 and 8.7 and alkalinity ranged from 8 to 22 mg/L as $CaCO_3$. Although tank 5 from Phase IB (Section 7) (pH of 8.5 and 0.3 mg/L zinc) gave the best results with respect to calcium and asbestos fiber counts, the required pH increase was not deemed practical for the field test because of control equipment complexity. The Phase IB recirculation tests showed that zinc solubility at pH 8 was nearly the same as that at pH 8.5, approximately 0.1 mg/L as zinc. This is in contrast to predictions made from the REDEQL computer model, which calculated the equilibrium concentration should have been about 0.5 mg/L at pH 8. The goal of adding the zinc at the 0.6 mg/L concentration was to exceed the soluble amount and precipitate zinc onto the asbestos-cement pipe walls to form a protective coating. Another concern was maintaining these zinc concentrations throughout the test area, analogous to maintaining a chlorine residual throughout a distribution system.

## Equipment and Setup

The chemical feed system (Figures 33 and 34) installed at the Clyde Hill pump station consisted of a metering pump with a speed control system. The zinc chloride was fed from a drum stored outside the pump station into the metering pump, and then into the water main. Mixing was accomplished using the natural turbulence in the pipe. The speed control system converted the signal from the flow meter on the water main into metering pump speed. In this way, the zinc feed system could vary the dose in proportion to the flows in the Clyde Hill distribution system. The average water flow in the distribution system was about 757 l/min (200 gpm), with peak day flows of about 1893 l/min (500 gpm).

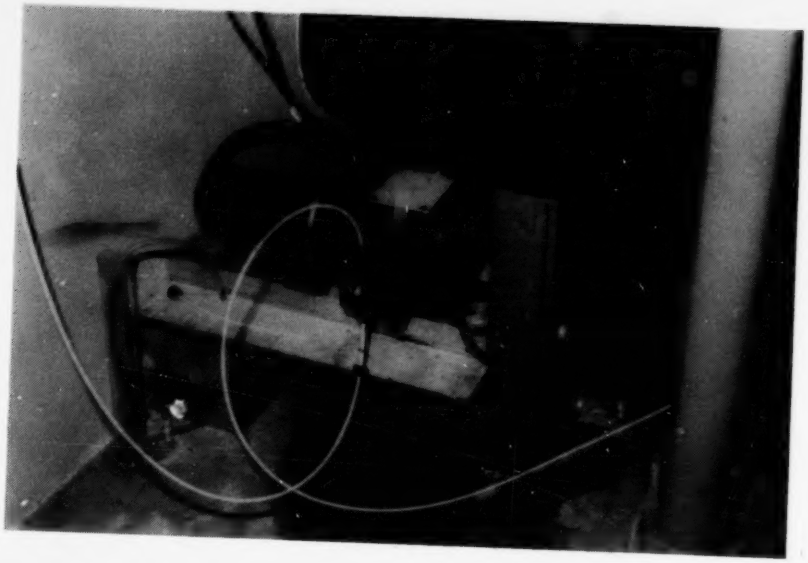
Although zinc chloride was available in an anhydrous form, the liquid form was chosen because the required chemical feed system was simpler. The liquid zinc chloride was available in a 65 percent zinc chloride solution costing about $1.10/kilogram ($.50 per pound). With an average flow of 757 l/min (200 gpm) the average zinc chloride dose was about 1.4 kilograms per day (3 pounds per day) to maintain an average concentration of 0.6 mg/L zinc.

An initial dose of zinc above the 0.6 mg/L steady state value was considered as a startup measure. However, it was decided against doing so in order to avoid any possible adverse impacts to consumers.

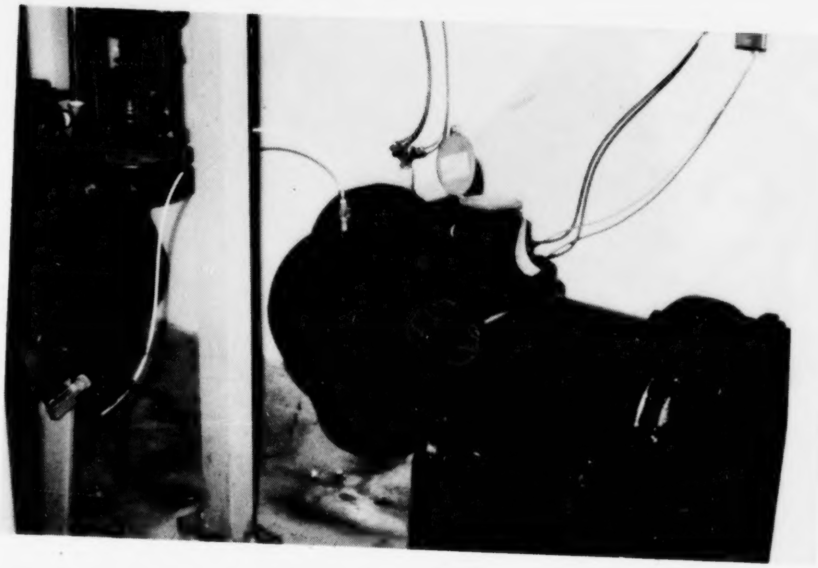
## TABLE 35

## PHASE II SAMPLING SCHEDULE

| Sampling Location | Monthly |  |  | Quarterly |
|---|---|---|---|---|
|  | General Mineral | Asbestos | Total Zinc Only | Particulate Zinc |
| Clyde Hill |  |  |  |  |
| CH1 | X | X |  |  |
| CH1A | X | X |  |  |
| CH2 | X | X |  |  |
| CH3 |  |  |  | X |
| CH4 |  |  |  | X |
| S1 |  |  | X |  |
| S2 |  |  | X |  |
| Control Area |  |  |  |  |
| D3 | X | X |  |  |
| D4 | X | X |  |  |



THE ZINC CHLORIDE CHEMICAL METERING PUMP
FIGURE 33



THE ZINC CHLORIDE INJECTION POINT
ON THE CLYDE HILL WATER MAIN
FIGURE 34

In addition to the chemical feed system, 0.9-meter (3-foot) lengths of new asbestos-cement and mortar-lined asbestos-cement pipes were installed with the intent of removing and inspecting them at the end of the field test. Asbestos-cement pipe sections were installed at locations CH1A, CH2, D3, and D4. Mortar-lined asbestos-cement pipe sections were installed at locations CH1A, CH2, and D3. Unused sections of both types of pipe were kept for later comparison. All installed pipe sections were placed directly in-line; that is, no special side loops were created.

## Impacts of Zinc Addition

The potential impacts studied were divided into two categories: domestic and industrial. Although the immediate concern was for the residents in Clyde Hill, which is primarily residential, industrial impacts were studied as a prelude to potential city-wide zinc application.

### Domestic Impacts

The primary domestic concern was the health issue. However, the 0.6 mg/L zinc dose was at least an order of magnitude below the 5 mg/L secondary standard for zinc set by the USEPA. There is no primary or health-related standard for zinc. A more serious concern was kidney dialysis. Contacts with a dialysis center in the Los Angeles area revealed that dialysis machines pretreat their water with either reverse osmosis or ion exchange. Therefore, the only major problem would be a more frequent change of either the reverse osmosis or the ion exchange cartridges. The third concern was for aquarium fish which might be sensitive to the zinc levels in the water. EPA (July 1976) has indicated that the 96 hour TL50 is less than 1 mg/L for some common varieties of aquarium fish. However, Netzer and Norman (1973) state that activated carbon filters used by aquarium hobbyists would remove zinc down to 0.03 mg/L from a stock solution at 10 mg/L within the pH range of 4 to 10. A similar field test using zinc orthophosphate in Greenwood, South Carolina, which began with 3 mg/L zinc and ended with 0.03 mg/L, resulted in no complaints from aquarium owners during the test (Grubb, March 1981). Likewise no complaints of loss of aquarium fish were received throughout the course of the Bellevue field test.

The City of Bellevue sent out a brief notification to the Clyde Hill residents informing them of the corrosion control project. As a result of this notification, only five phone calls were received; all callers asked non-controversial questions concerning the study. A council meeting, held for the City of Clyde Hill in early March 1983 just before the start of the test, was attended by Bellevue and JMM staff. The City of Bellevue summarized the project for those attending. Most of the people attending agreed that the project was probably beneficial.

### Industrial Impacts

There was no immediate concern with regard to industrial impacts because the Clyde Hill area was entirely residential. However, if the zinc chloride addition were extended to the rest of the City of Bellevue, industrial impacts would have to be considered.

Greenwood, South Carolina had problems with zinc orthophosphate clogging the filters of a local pharmaceutical firm (Grubb, 1981). Under normal conditions, these filters lasted six to seven months without clogging. However, with the addition of zinc orthophosphate, the filters began clogging in two to three days. Even when the dose was reduced from 3 mg/L as zinc in the startup to 0.3 mg/L used in the remainder of the project, some clogging still was encountered. Zinc orthophosphate was used in the Greenwood, South Carolina project (at a higher initial dose) rather than zinc chloride. It is not certain whether the same effect would occur in Bellevue.

A second consideration was photographic laboratories. Eastman Kodak indicated that adverse impacts were only encountered after the zinc concentration exceeded 10 mg/L as zinc. Other industries such as electronics and soft drink industries should be contacted if a city-wide application of zinc chloride is planned.

A final concern was the 11.8 kg/day (26 lb/day) zinc discharge limit placed on the Seattle Metro Wastewater Treatment Plant in Renton to which Bellevue connects its sewer lines. Located south of Bellevue in the Seattle area, the Renton plant discharges into the Green River. During the field test the maximum zinc output from Clyde Hill on peak days was estimated to be 1.4 kg/day (3 lb/day) conservatively assuming all zinc reached the sewer. While this weight of zinc would not seriously affect the treatment plant discharge, zinc application throughout Bellevue might, since the water usage in the City of Bellevue is over an order of magnitude greater than that of Clyde Hill. However, if plans to change the point of discharge to Puget Sound in 1987 are carried out, there would no longer be a zinc limitation. City-wide implementation of zinc would warrant more investigation of this issue before proceeding.

## RESULTS AND DISCUSSION

The field test results are divided into individual topics where they are discussed in detail. At the beginning of this section are descriptions of the startup events and the Seattle Corrosion Control Program. Since Bellevue receives its water from the Seattle water supply system, any form of water treatment such as corrosion control at the water sources or along the supply line, would affect Bellevue and consequently the field test. Next, the main body of the results are discussed individually, including asbestos, the physical hardness testing, changes in water quality, and the behavior of the added zinc. Finally, this section concludes with a cost comparison between zinc chloride and various other alternatives such as replacing the A/C pipe with other materials.

### Startup

The first zinc chloride doses into the Clyde Hill system began on March 30, 1983. The following startup protocol was followed to insure that the proper dose was applied:

> First Week of Operation. On the first two days, the chemical feed pump would be operated only long enough to take a sample at CH1A to check the zinc dose. Continuous chemical feeding would begin only after two consecutive days of proper dosing. Daily samples would be taken when continuous feeding started. Also, daily records of the zinc chloride level in the storage drum would be kept. If the dose was low, adjustments would be

made, but operation would continue. However, if the dose was higher than 1 mg/L, operations would stop until the problem was fixed. Any consumer complaints related to zinc would be handled immediately by Bellevue personnel who would sample at the home or homes affected. Chemical feed would be discontinued after the samples were taken.

Second Week of Operation. Samples would be taken twice a week at CH1A to monitor zinc concentrations.

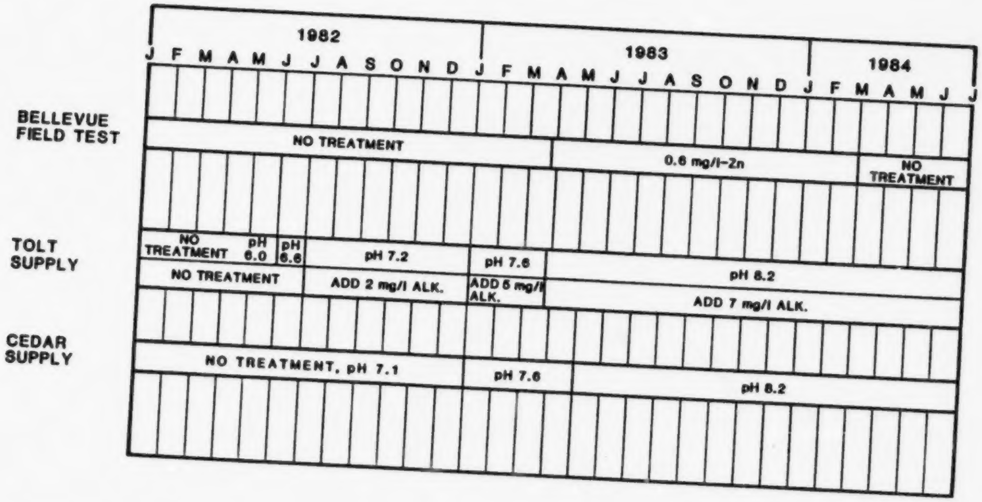
Third and Fourth Week of Operation. Samples would be taken once a week at CH1A to monitor zinc concentrations. After four weeks, samples would be taken routinely on a monthly basis.

An initial problem with a loss of prime in the chemical feed system was overcome by changing a leaking valve in the feed line, and the feed system was in continuous operation by April 14, 1983. Concern was raised over feed pump non-operation when water flow rates were below 605 l/min (160 gpm). However, this did not become a significant problem during the field test. No consumer complaints related to the zinc chloride treatment were received throughout the field test.

## Seattle Corrosion Control Program

The Phase II field test was designed under the assumption that the Seattle Corrosion Control Program would be in full operation since results would be more meaningful to long-term strategies for Bellevue. The Seattle Corrosion Control Program was designed to protect metallic pipes and not necessarily asbestos-cement pipes. The schedule for both the Cedar and Tolt supplies corrosion control program is shown in Figure 35. However, the water entering Clyde Hill was only from the Tolt supply. Figure 35 shows that the startup of the corrosion control program was incremented, with gradual increases in pH and alkalinity addition until pH reached 8.2. By the end of March 1983, 7 mg/L of alkalinity was added into the Tolt system. Due to delays in earlier corrosion control program schedules, it was necessary to meet project schedule constraints by starting the field test as soon as the corrosion control program had reached its final pH and alkalinity values. In retrospect, had more time been available, it might have been more prudent to allow the Seattle corrosion control program about six months operating time before starting the field test to allow the A/C pipes to equilibriate with the new water conditions.

The effects of the Seattle corrosion control on the water reaching the Bellevue area are shown in Figures 36 through 38. Figure 36 shows the change in pH over the control section (D3 to D4) before and after the Seattle Corrosion Control Program. Samples taken before the start of the Seattle Corrosion Control Program were part of the distribution system characterization in Phase IA of this study (Section 6). In general, outlet values (at D4) were still higher than inlet values (at D3) indicating that A/C pipe deterioration was still occurring, at least in the first year of the Seattle Corrosion Control Program. Figure 36 shows a dramatic increase in the pH at both the inlet (D3) and outlet (D4) of the control section. Figure 37 shows the alkalinity change due to the Seattle Corrosion Control Program. Some of the high peaks in both Figures 37 and 38 are attributed to the periodic presence of Cedar water in the control section. This would account for the apparent increase in pH and alkalinity even before the Seattle



THE BELLEVUE ASBESTOS CONTROL FIELD TEST
AND THE SEATTLE CORROSION CONTROL PROGRAM

FIGURE 35

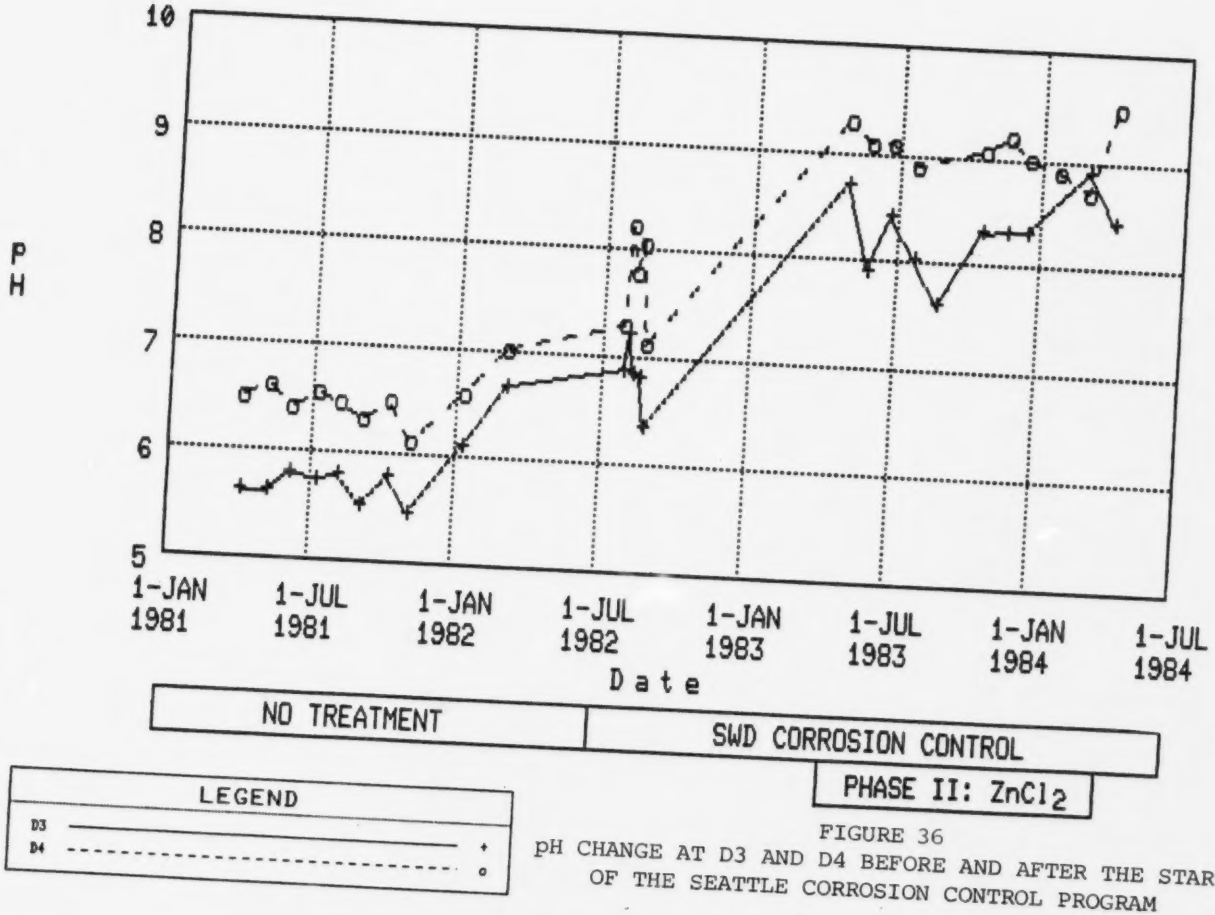


FIGURE 36
pH CHANGE AT D3 AND D4 BEFORE AND AFTER THE START OF THE SEATTLE CORROSION CONTROL PROGRAM

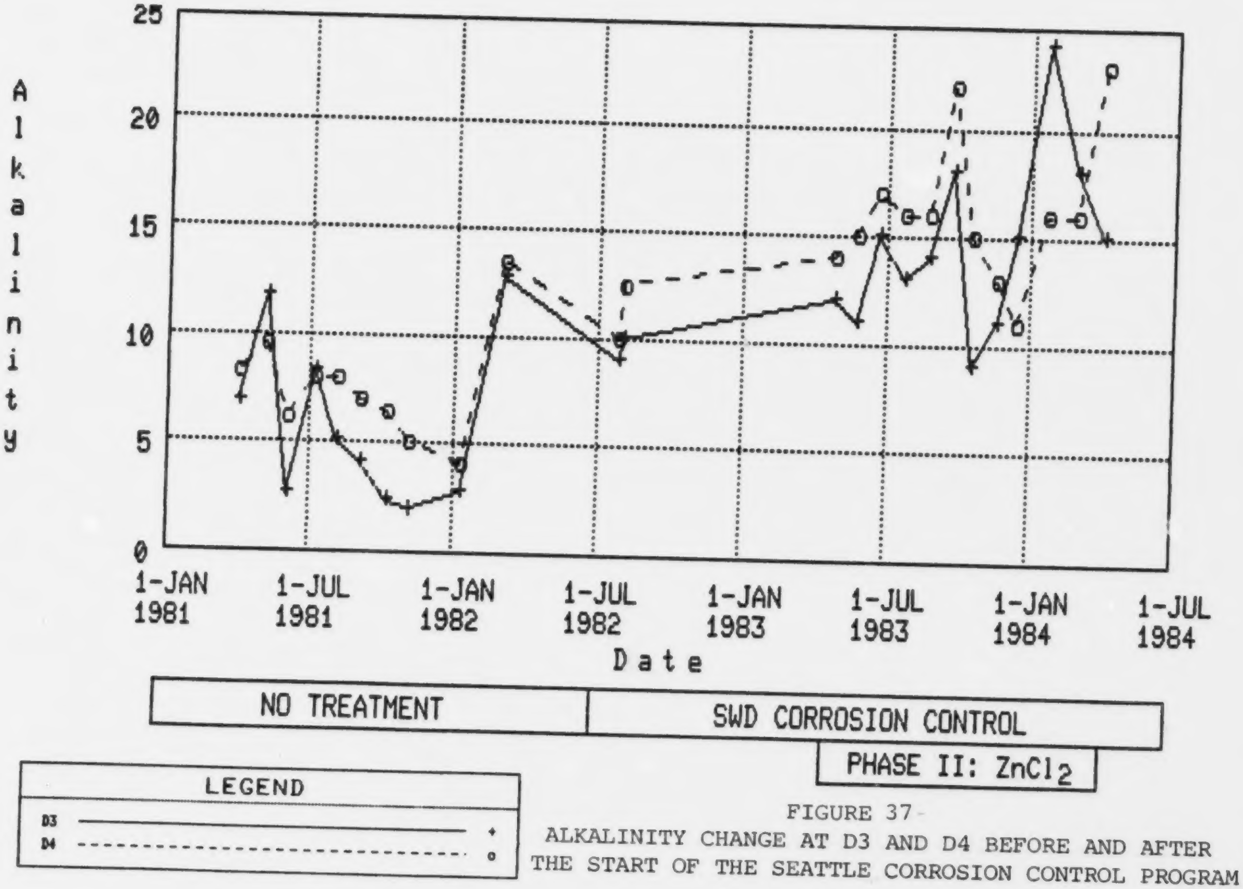


FIGURE 37

ALKALINITY CHANGE AT D3 AND D4 BEFORE AND AFTER THE START OF THE SEATTLE CORROSION CONTROL PROGRAM

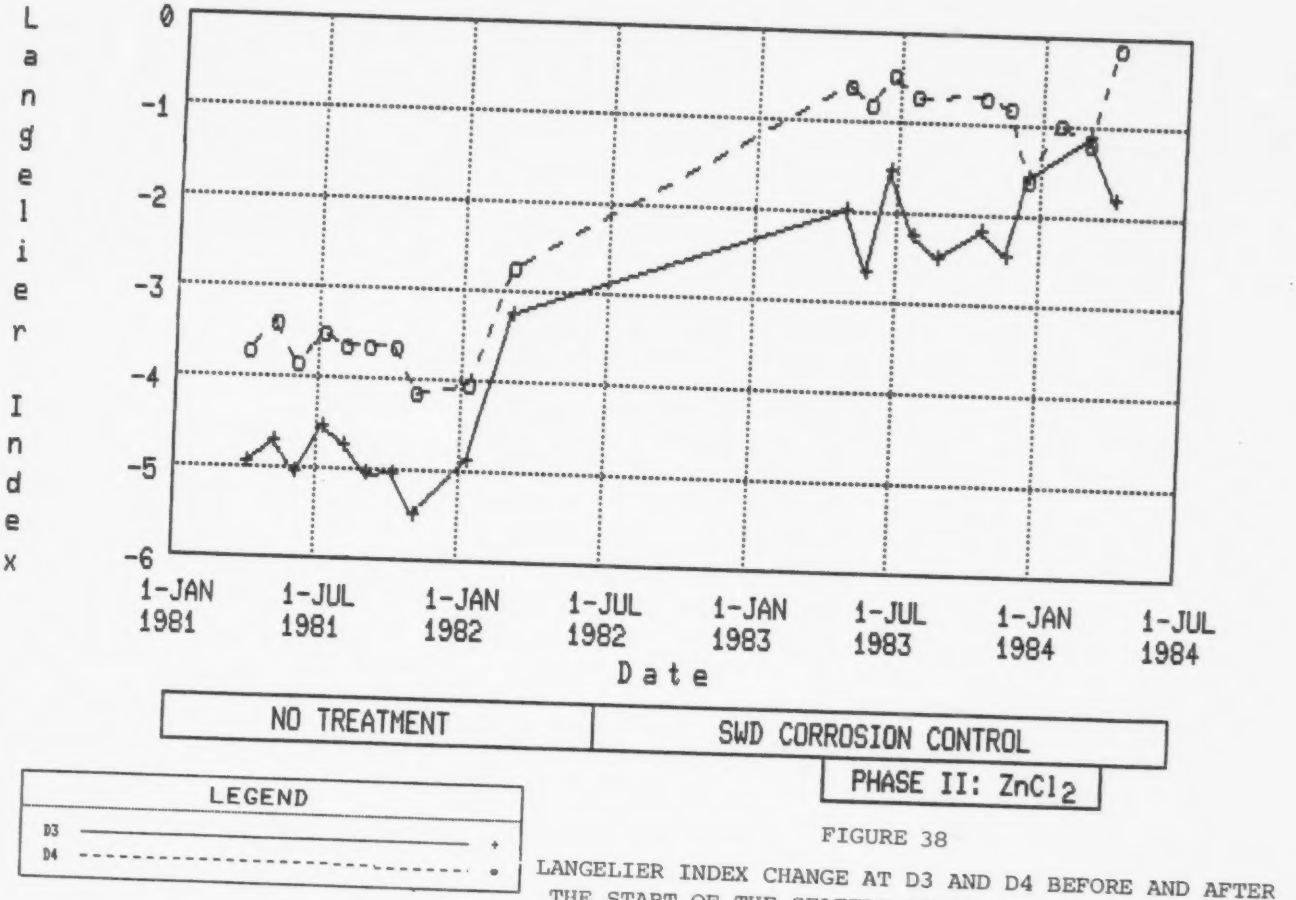


FIGURE 38

LANGELIER INDEX CHANGE AT D3 AND D4 BEFORE AND AFTER THE START OF THE SEATTLE CORROSION CONTROL PROGRAM

Corrosion Control Program started. Figure 38 shows the change for the Langelier Index in the control section. The Langelier Index at the inlet increased from an extremely low value of -5 at the inlet to -2 after Seattle's treatment. Again, brief influxes of Cedar water probably caused the increase just before the start of the Seattle Corrosion Control Program.

## Asbestos Results

Initial results (Figures 39, 40) in the first few months of the field test suggested fewer asbestos fibers were released from the zinc chloride test section compared to the control. However, later behavior of the control section (D3 to D4) shown in Figure 39 indicates that the Seattle Corrosion Control Program itself may be causing some protection for the asbestos-cement pipes, as shown by results after about seven months of the Phase II field test. The beginning of the field test is also shown on the graph for reference. The behavior of the Clyde Hill test section shown in Figure 40 is similar in later months, i.e. a decrease in the asbestos fiber counts after seven months of field tests. There were, however, some anomalous asbestos concentrations in November 1983 and April 1984. There were about an order of magnitude above the majority of the other points, suggesting that perhaps some sediment got into the samples. A check of service records indicated no known flushing or tapping had occurred in the area, but perhaps a water hammer or a rapid change in flow could stir up debris in the bottom of a pipe. CH2 was a continuous flowing sample site; therefore, it is unlikely that a sampling error had occurred at that point.

When the results for the test area and the control area are superimposed, as shown in Figure 41, it is noted that the reduction in asbestos fibers occurs for both areas at about the same time in the project. Therefore, the reduction in asbestos fiber counts may be due to the Seattle Corrosion Control Program; the effect of the zinc chloride treatment is uncertain at this point. Further analysis using cumulative probability plotting in Figure 42 also indicates that both the test area and the control area behaved similarly. In addition, coupon tests in Weston, Wisconsin (EPA, 1984) using zinc chloride could not find any added benefits from using zinc chloride, but that conclusion was based on hardness tests rather than asbestos analysis. The researchers suspected that the result was due to sequestering polyphosphates used for iron and manganese control. Polyphosphates are not used in Bellevue water.

The lime addition for pH adjustment and the soda ash for alkalinity adjustment may have affected the silicate and aluminate chemistry of the A/C pipe matrix. This was seen in the Phase 1B recirculation tests in which tanks T-3 and T-4 simulating the Seattle Corrosion Control Program each experienced reductions in calcium and silica pickup relative to the control. What may be occurring is a rise in calcium concentration and pH caused by the lime addition. This may slow the leaching of calcium from the pipe matrix as suggested by others (Schock and Buelow, 1981); however, there was no evidence in the Phase IB recirculation study that pH and alkalinity adjustment reduced asbestos fiber release.

Since CH1 and CH1A were only a short distance apart, asbestos samples taken at both locations could be used as a measure of precision in asbestos sampling and analysis. The results are shown in Figure 43. They indicate that for the most part asbestos analysis

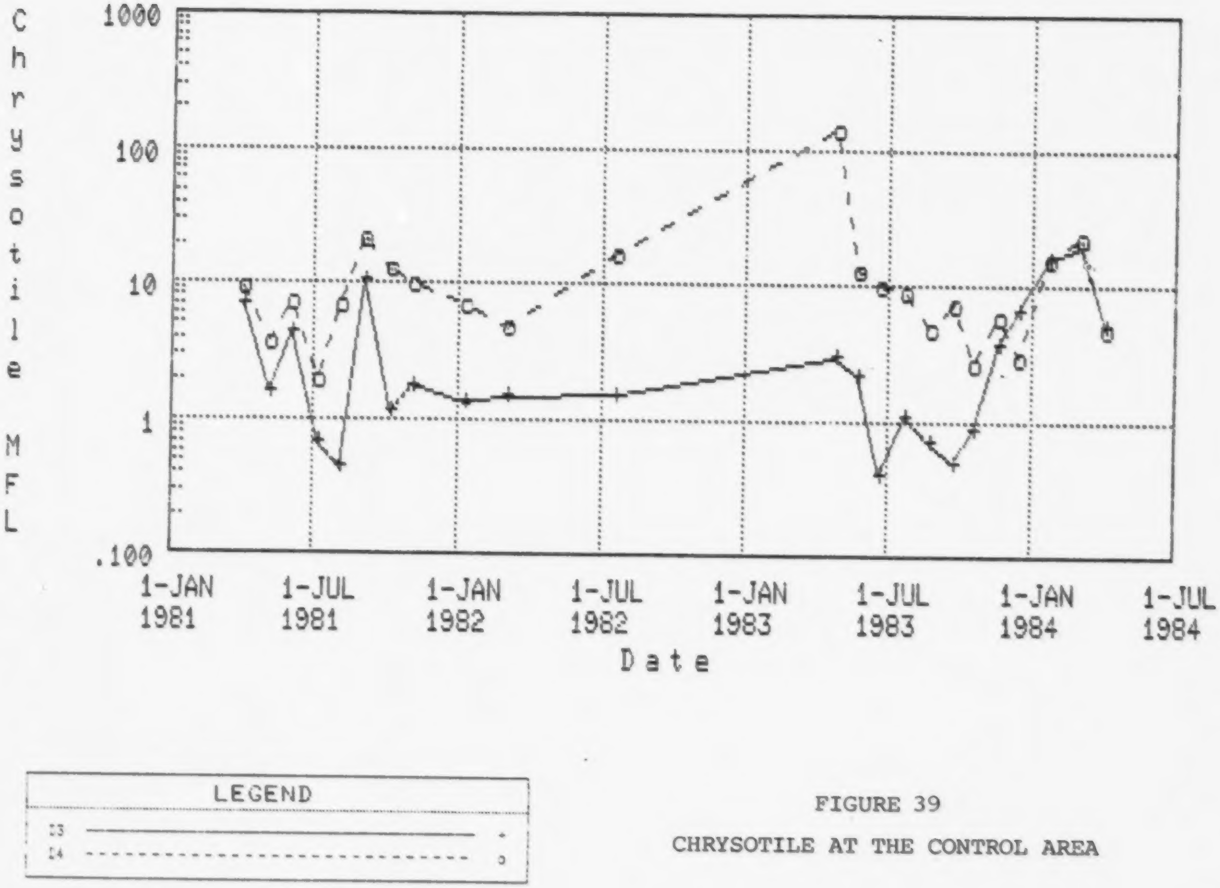


FIGURE 39

CHRYSOTILE AT THE CONTROL AREA

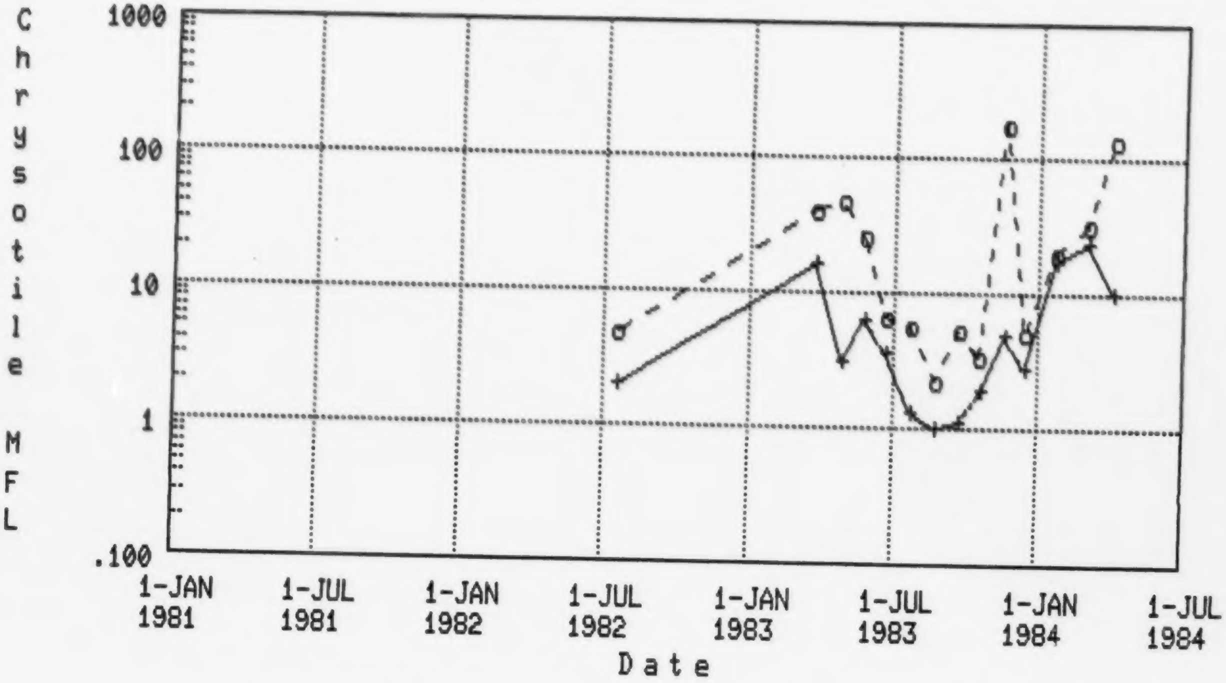


FIGURE 40

CHRYSOTILE AT THE TEST AREA

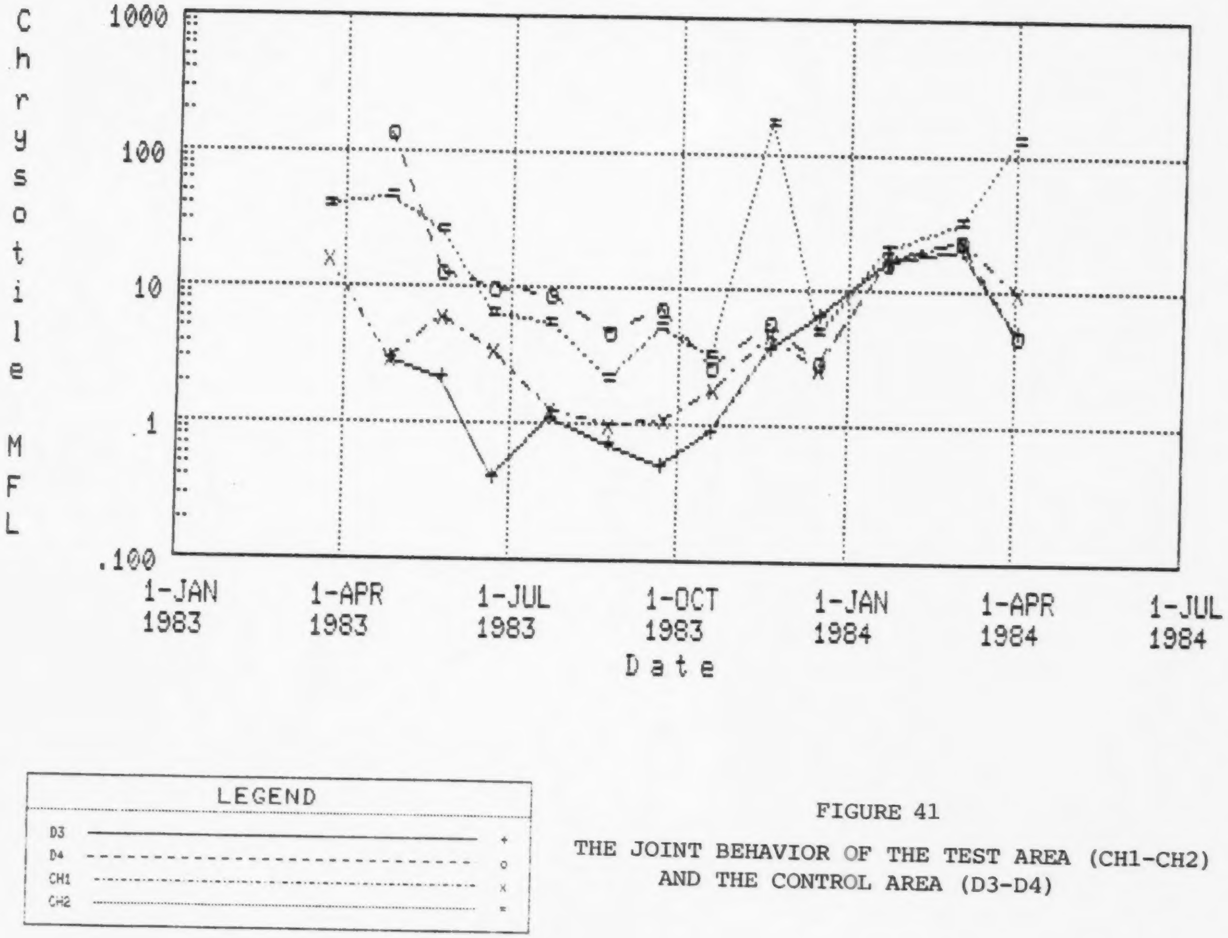
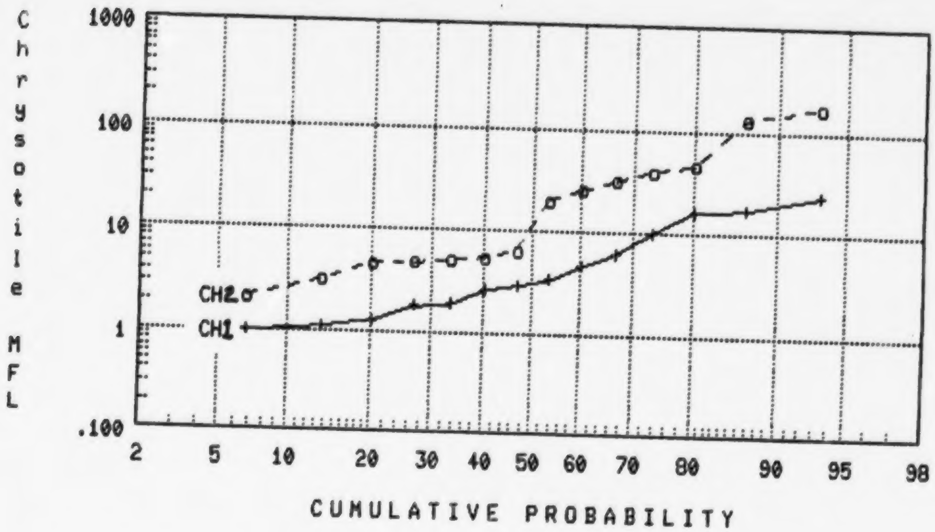


FIGURE 41

THE JOINT BEHAVIOR OF THE TEST AREA (CH1-CH2)
AND THE CONTROL AREA (D3-D4)



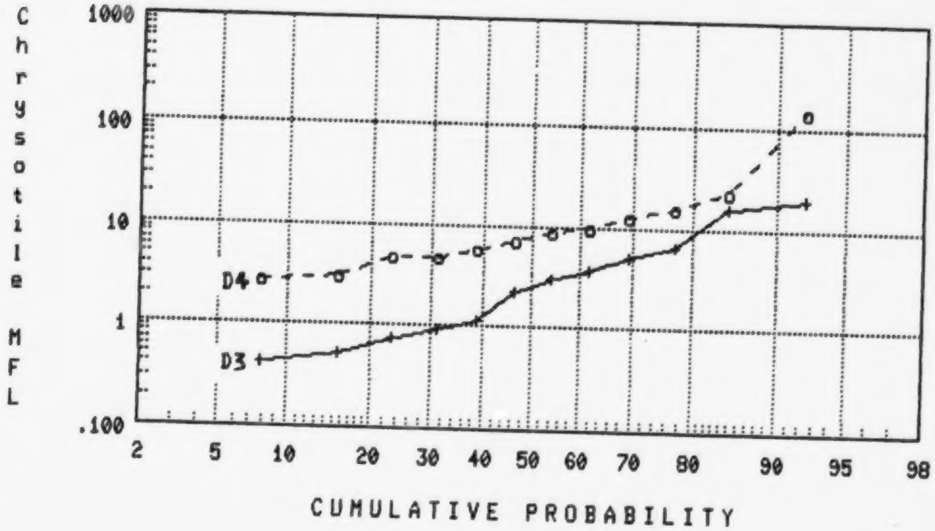


FIGURE 42

CUMULATIVE PROBABILITY ANALYSIS FOR THE TEST AREA (CH1-CH2) AND THE CONTROL AREA (D3-D4)

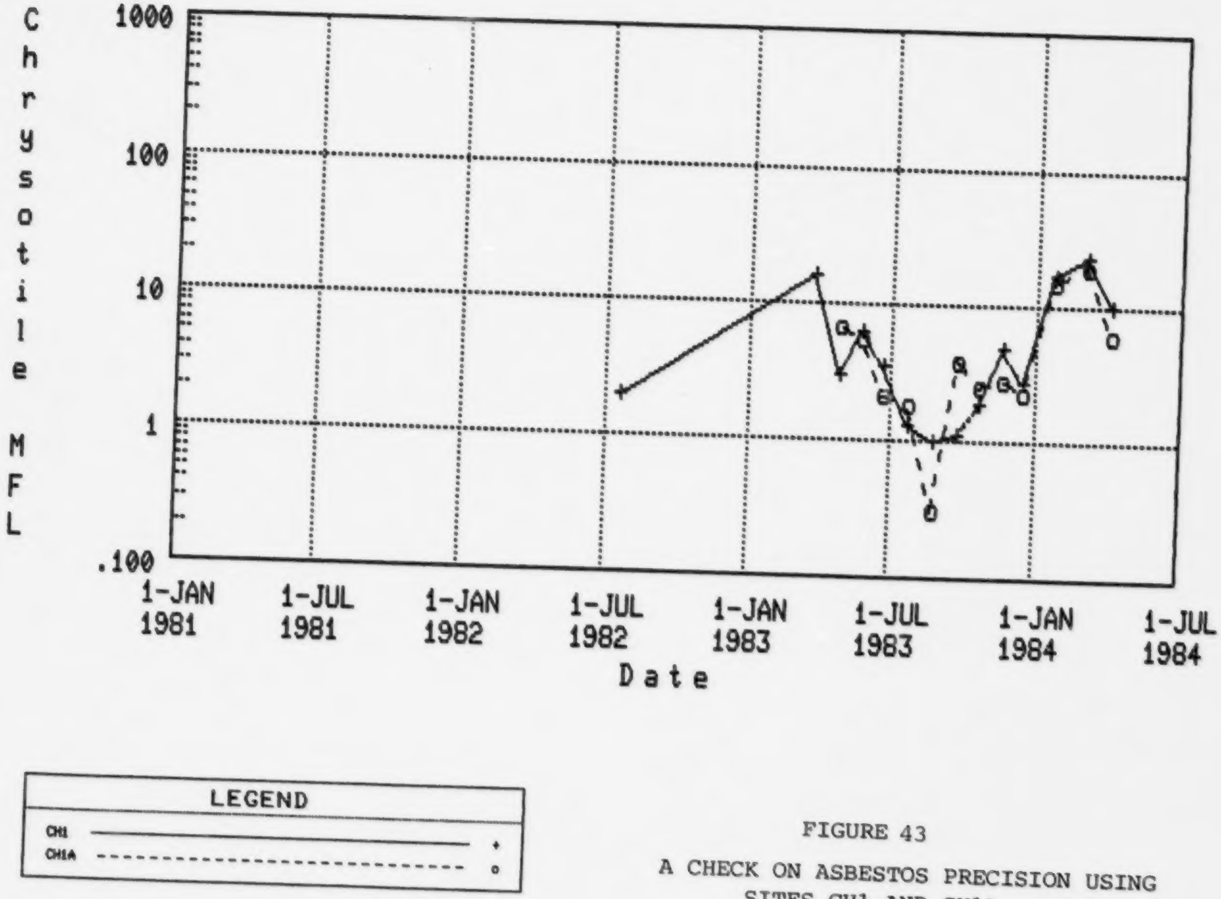


FIGURE 43

A CHECK ON ASBESTOS PRECISION USING SITES CH1 AND CH1A had good precision; in most cases there was very little difference between the replicate results.

## Calcium Loss Analysis

Calcium loss from the asbetos-cement coupons removed from the field test was measured by scanning electron microscope line scans, conducted by the USEPA. With a precision of approximately 0.1 millimeters, no appreciable calcium loss could be detected on either the coupons subjected to the zinc chloride or the coupons from the control loop. In contrast, the recirculation tests of Phase IB showed calcium losses between 0.2 and 0.3 millimeters except for tanks 5 and 6 (zinc chloride addition), which showed no appreciable loss. These results further suggest that the Seattle Corrosion Control Program may be protecting the asbestos-cement pipe by virtue of the increase of the Langelier Index.

## Physical Hardness Testing Results

The new sections of asbestos-cement pipe which were placed at CH1A, CH2, D3 and D4 were removed at the end of the field test. These pipe sections were cut into coupons and subjected to hardness testing as described in Section 5. Samples were sent to Northwest Laboratories in Seattle with a duplicate set sent to the USEPA. The test results are summarized in Tables 36 for the Shore "D" test and 37 for the Rockwell "L" test. The analysis of variance (ANOVA) show that there was no significant difference between the used and unused sections of asbestos-cement pipe. The reason for the lack of difference between the pipes is due to the high variation within groups (i.e., locations) of samples overshadowing changes due to use. Inspecting the standard deviations in Tables 36 and 37 for both Shore "D" and Rockwell "L" data reveals that a real change of hardness of at least five to 10 percent of the original value is necessary before it can be easily distinguished from normal background variation. This may take two to five years. Also, the variation among replicate samples at a given location suggests that inhomogeneities in a single pipe make it necessary to take several coupons from a pipe to get a representative hardness value. It is unfortunate that the extent of this variation among replicates was not fully understood until the field test was complete.

The USEPA Shore "D" tests were conducted using a modified durometer described elsewhere (Millette, Logsdon, 1984) which had a curved rather than flat bottom. The curvature allowed better contact with the A/C coupon. In contrast, the normal flat-bottomed durometer would leave space between the specimen and would thus register a false penetration. This explains the difference between the standard durometer results and those for the modified durometer evident in Table 36.

Shore "D" hardness tests for the mortar-lined A/C pipe shown in Table 38 did show a significant difference due to location. Since the mortar does not contain asbestos, this result is not indicative of fiber release, but may indicate some changes in the physical character of the mortar. The Rockwell "L" hardness test in Table 39 did not show a significant difference due to a large variation within groups. This variation may be related to a crushing or snapping noise reported by the analyst while conducting the test. This may be due to voids between the mortar and the asbestos-cement collapsing

## TABLE 36

## SHORE D HARDNESS TEST FOR A/C PIPE

| Standard Durometer | | | | | Modified Durometer (EPA) | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Unused A/C | D3 | D4 | CH1A | CH2 | Unused A/C | D3 | D4 | CH1A | CH2 |
| 74 | 77 | 77 | 81 | 76 | 94 | 91 | 93 | 90 | 92 |
| 81 | 78 | 77 | 86 | 79 | 96 | 92 | 91 | 96 | 93 |
| 80 | 81 | 76 | 76 | 72 | 96 | 92 | 91 | 74 | 94 |

**Standard Durometer Analysis of Variance**

| | Degrees of Freedom | Sum of Squares | Mean Square |
|---|---|---|---|
| Factor | 4 | 50.3 | 12.6 |
| Error | 10 | 112.7 | 11.3 |
| Total | 14 | 162.9 | |

F-value = 1.12

Conclusion: The difference between the means is not significant at the 5% level.

**Modified Durometer Analysis of Variance**

| | Degrees of Freedom | Sum of Squares | Mean Square |
|---|---|---|---|
| Factor | 4 | 124.2 | 31.1 |
| Error | 10 | 262.8 | 26.3 |
| Total | 14 | 387.0 | |

F-value = 1.18

Concluson: The difference between means is not significant at the 5% level.

## TABLE 37

## ROCKWELL L HARDNESS TEST FOR A/C PIPE

### Rockwell L

| Unused A/C | D3 | D4 | CH1A | CH2 |
|---|---|---|---|---|
| 83 | 86 | 87 | 96 | 90 |
| 98 | 86 | 88 | 95 | 92 |
| 96 | 89 | 85 | 91 | 87 |

### Rockwell L Analysis of Variance

| | Degrees of Freedom | Sum of Squares | Mean Square |
|---|---|---|---|
| Factor | 4 | 124.9 | 31.2 |
| Error | 10 | 170.0 | 17.0 |
| Total | 14 | 294.9 | |

F-value = 1.84

Conclusion: The difference between the means is not significant at the 5% level.

### Rockwell L (EPA)

| Unused A/C | D3 | D4 | CH1A | CH2 |
|---|---|---|---|---|
| 100 | 89 | 96 | 101 | 95 |
| 93 | 91 | 95 | 94 | 94 |
| 102 | 87 | 97 | 76 | 94 |

### Rockwell L (EPA) Analysis of Variance

| | Degrees of Freedom | Sum of Squares | Mean Square |
|---|---|---|---|
| Factor | 4 | 176.7 | 44.2 |
| Error | 10 | 433.2 | 43.3 |
| Total | 14 | 609.9 | |

F-value = 1.02

Concluson: The difference between means is not significant at the 5% level.

## TABLE 38

## STANDARD DEVIATIONS ENCOUNTERED

| | Standard Deviation | Total Hardness* |
|---|---|---|
| Shore D | 3.4-5.3 | 74-81 (94-96)** |
| Rockwell L | 4.6-6.6 | 83-102 |

* Unused A/C
** Modified Durometer

## TABLE 39

## ROCKWELL "L" HARDNESS TEST FOR MORTAR-LINED A/C PIPE (EPA Data)

| Rockwell "L" | | | | |
|---|---|---|---|---|
| **Unused Mortar A/C** | **CH1A** | **CH2** | **D3** | **Tolt** |
| 98.1 | 91.2 | 84.0 | 98.2 | 85.7 |
| 55.1* | 75.8 | 91.7 | 77.0 | 75.1 |
| 55.3* | 89.6 | 82.2 | 86.7 | 64.9 |

### ANALYSIS OF VARIANCE

| | Degree of Freedom | Sum of Squares | Mean Square |
|---|---|---|---|
| Factor | 4 | 749.9 | 187.5 |
| Error | 10 | 1862.9 | 186.3 |
| Total | 14 | 2612.8 | |

F-Value = 1.01

Conclusion: The difference between the means is not significant at the 5% level.

* Suspected to be abnormally low.

under the total 70 kilogram load. The Shore "D", with a much lower load, did not have this problem.

## Other Water Quality Parameters

One necessary condition for the field test was that the test area and the control both had to receive water from the Tolt water supply. If one section received some Cedar water, it is necessary for the other section to also receive Cedar water at the same time. Comparisons between the test area and control area are summarized in Figures 44 through 47 some of the major water quality parameters. pH is shown in Figure 44 for the inlets to both the test section and control section. For the most part, the pH of the two areas is similar. Alkalinity (Figure 45) also shows that the two areas are behaving similarly. One exception is noted in the February 1984 sample which shows that the control area might have been receiving Cedar water while the test area was receiving Tolt water. Figure 46 shows the temperature behavior of both areas and again indicates that the same waters were going to both areas. Finally, Figure 47 shows the TDS to be similar in both areas.

Table 40 summarizes all water quality parameters giving the medians, means, and standard deviations, and number of data points. Phase IA data are included for comparison. In general, the parameters showing increases after exposure to A/C pipe (chrysotile, pH, alkalinity, calcium, silica, TDS, hardness, and Langelier Index) were the same as those noted in Phase IA.

Water passing through asbestos-cement pipe had an increase in pH and alkalinity as seen in Figures 36 and 37. This is probably due to the release of calcium and silica from the pipe matrix which also releases hydroxide, as noted by Shock and Buelow (1981). One question that arose in the field test was whether or not the release of calcium and silica was decreased in the control section due to the Seattle Corrosion Control Program. Tables 41 and 42 contain t-test analyses for both calcium and silica. The t-tests show that the decreases noted were not statistically significant at the five percent level. However, had more samples been taken, the difference might have been shown to be significant considering that the Phase 1B recirculation tests showed a decrease in the calcium and silica release done with pH and alkalinity increase.

## Behavior of the Added Zinc

Another question for this project is whether or not the added zinc is deposited in the Clyde Hill pipe network. Figure 48 shows the zinc concentrations just after chemical addition and at the end of the system. The zinc concentration at the point of chemical addition hovers just above the target zinc concentration of 0.6 mg/L as zinc. In contrast, the zinc concentrations at the end of the system at sampling point CH2 are about 50 percent less than the original dose. This indicates some accumulation in the system. A mass balance for zinc in the Clyde Hill system was also conducted. The mass balance itself is diagramed in Figure 49 showing the inputs and outputs of zinc from the system. The numerical results for the mass balance are summarized in Table 43. They show that approximately 32 percent of the zinc is staying in the system. The accumulation is probably accurate to a factor of two and is based on several assumptions. The first assumption is an 11 percent delivery loss of water due to

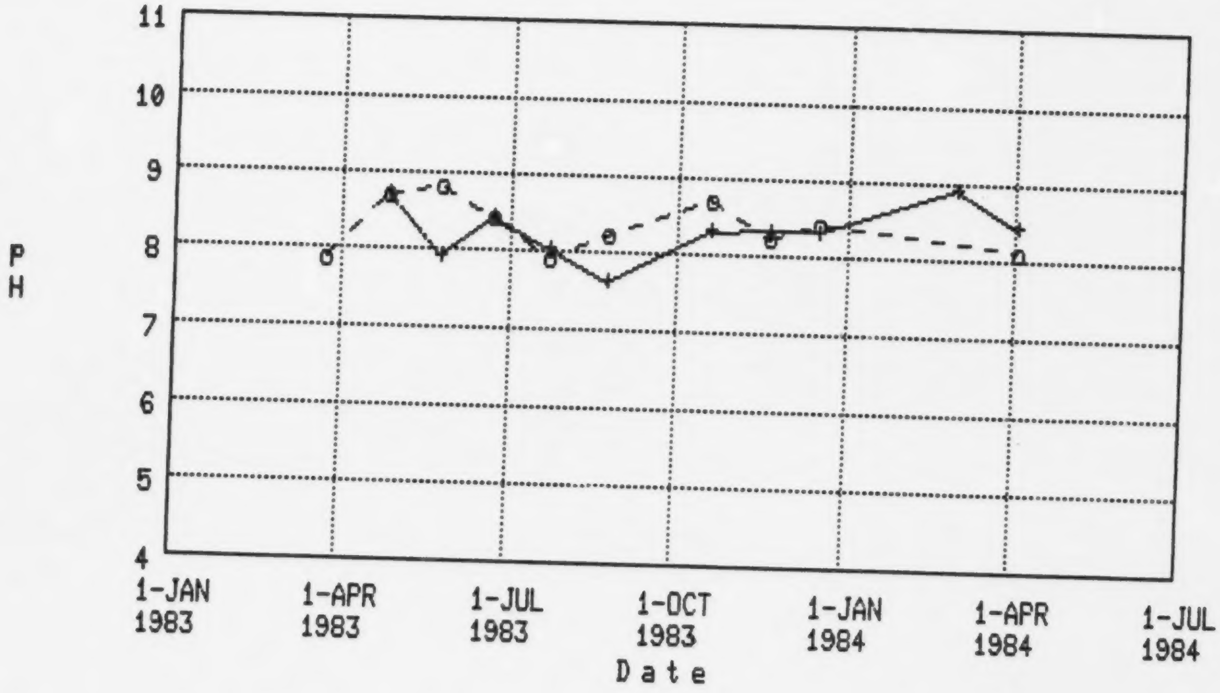


FIGURE 44

pH BEHAVIOR AT THE INLETS TO THE TEST AREA (CH1)
AND THE CONTROL AREA (D3)

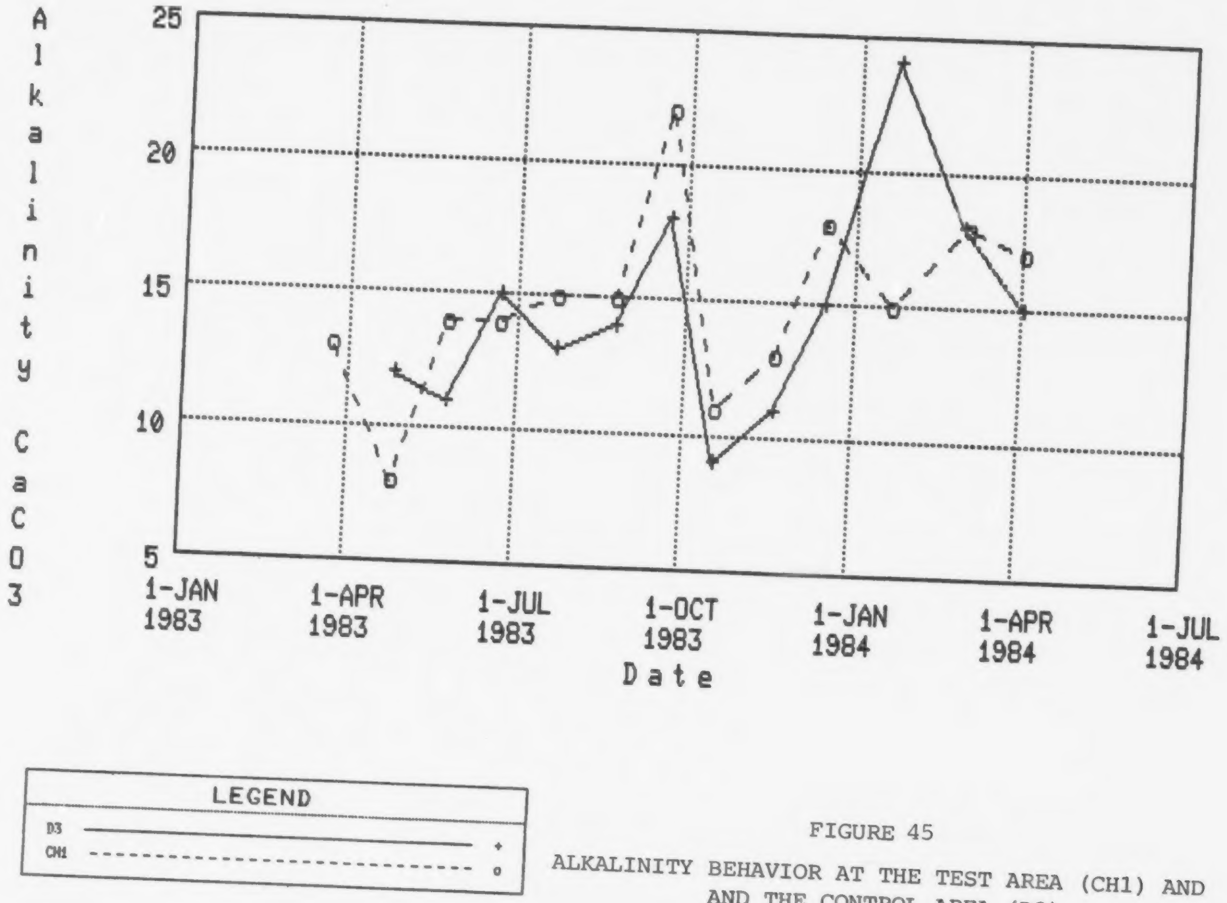


FIGURE 45

ALKALINITY BEHAVIOR AT THE TEST AREA (CH1) AND AND THE CONTROL AREA (D3)

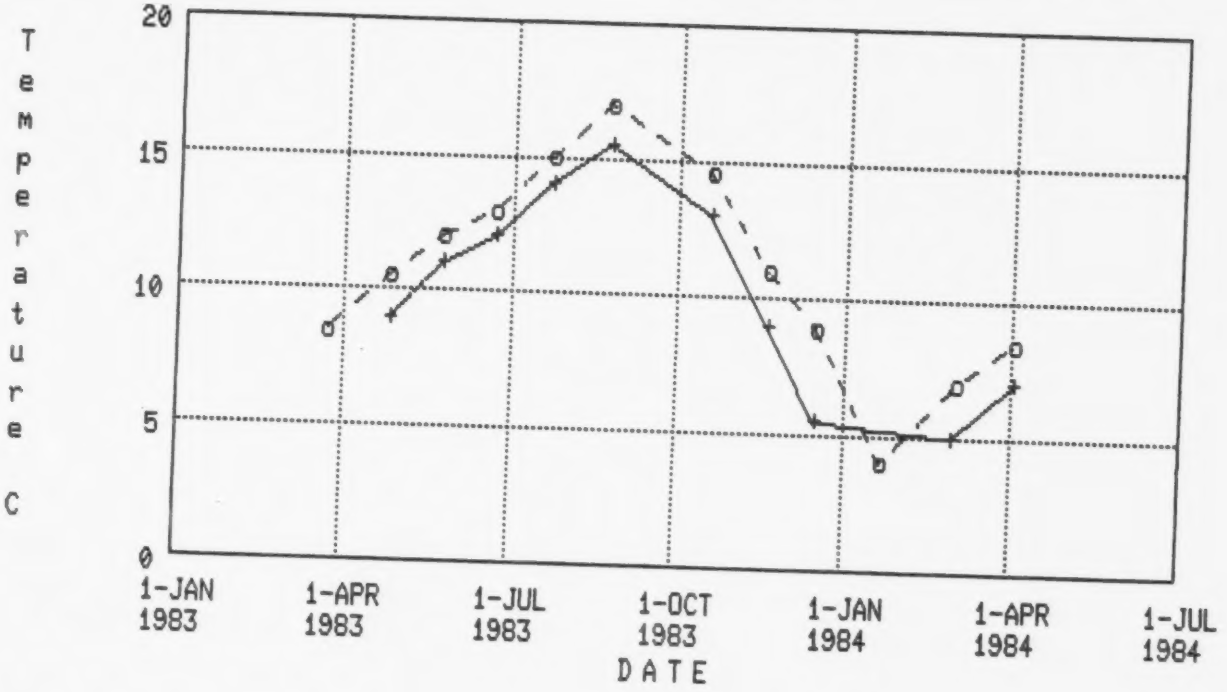


FIGURE 46

TEMPERATURE BEHAVIOR AT THE INLETS TO THE TEST AREA (CH1) AND THE CONTROL AREA (D3)

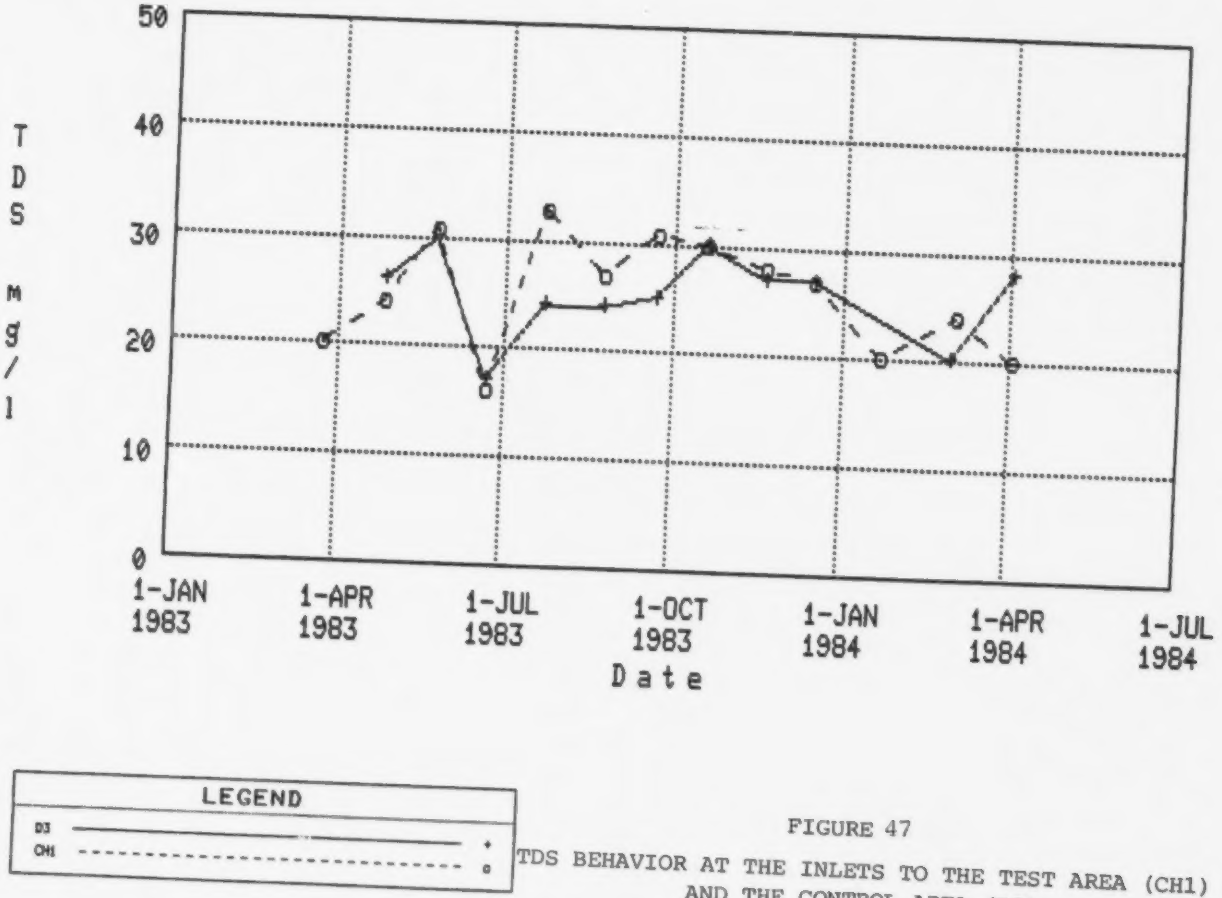


FIGURE 47

TDS BEHAVIOR AT THE INLETS TO THE TEST AREA (CH1)
AND THE CONTROL AREA (D3)

# TABLE 40

## WATER QUALITY PARAMETERS

| Parameter | Location | | Zinc | Phase I | | | | Phase II | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Median | Mean | S | N | Median | Mean | S | N |
| pH | | | | | | | | | | | |
| | Control | D3 | No | 5.7 | 5.8 | .36 | 10 | 8.3 | 8.3 | 0.4 | 10 |
| | | D4 | No | 6.5 | 6.5 | .23 | 10 | 9.1 | 9.1 | 0.2 | 10 |
| | Test | CH1 | No | — | | | | 8.2 | 8.3 | 0.3 | 10 |
| | | CH1A | Yes | — | | | | 8.3 | 8.4 | 0.3 | 9 |
| | | CH2 | Yes | — | | | | 8.8 | 8.7 | 0.4 | 10 |
| Alkalinity | | | | | | | | | | | |
| | Control | D3 | No | 4 | 5.8 | 4.0 | 10 | 14 | 15 | 4 | 12 |
| | | D4 | No | 7 | 7.6 | 2.6 | 10 | 16 | 16 | 3 | 12 |
| | Test | CH1 | No | — | | | | 15 | 15 | 3 | 13 |
| | | CH1A | Yes | — | | | | 15 | 16 | 3 | 12 |
| | | CH2 | Yes | — | | | | 16 | 16 | 3 | 12 |
| Calcium | | | | | | | | | | | |
| | Control | D3 | No | 2.4 | 2.8 | 1.0 | 10 | 3.9 | 3.9 | 0.6 | 12 |
| | | D4 | No | 4.1 | 4.4 | 0.9 | 10 | 4.7 | 5.0 | 0.8 | 12 |
| | Test | CH1 | No | — | | | | 4.1 | 4.4 | 1.1 | 13 |
| | | CH1A | Yes | — | | | | 4.1 | 4.4 | 0.8 | 12 |
| | | CH2 | Yes | — | | | | 5.4 | 5.4 | 0.7 | 13 |
| Chrysotile (MFL) | | | | | | | | | | | |
| | Control | D3 | No | 1.5 | 3.0 | 3.3 | 10 | 2.1 | 5.0 | 6.4 | 12 |
| | | D4 | No | 7.09 | 8.6 | 5.7 | 10 | 7.2 | 19.9 | 38.3 | 12 |
| | Test | CH1 | No | — | | | | 3.4 | 7.0 | 7.2 | 13 |
| | | CH1A | Yes | — | | | | 2.8 | 5.7 | 5.9 | 12 |
| | | CH2 | Yes | — | | | | 20.0 | 37.5 | 52.6 | 13 |

## TABLE 40 (Cont'd)

| Parameter | Location | | Zinc | Phase I | | | | Phase II | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Median | Mean | S | N | Median | Mean | S | N |
| Iron | | | | | | | | | | | |
| | Control | D3 | No | .056 | .084 | .048 | 10 | 0.079 | .088 | .039 | 12 |
| | | D4 | No | .081 | .104 | .038 | 10 | 0.091 | .098 | .068 | 12 |
| | Test | CH1 | No | — | | | | 0.069 | .076 | .037 | 13 |
| | | CH1A | Yes | — | | | | 0.097 | .115 | .069 | 12 |
| | | CH2 | Yes | — | | | | 0.072 | .084 | .065 | 13 |
| Magnesium | | | | | | | | | | | |
| | Control | D3 | No | 0.4 | 0.54 | .26 | 10 | 0.4 | .51 | .39 | 12 |
| | | D4 | No | 0.2 | 0.35 | .30 | 10 | 0.2 | .37 | .52 | 12 |
| | Test | CH1 | No | — | | | | 0.4 | .38 | .07 | 13 |
| | | CH1A | Yes | — | | | | 0.4 | .38 | .07 | 12 |
| | | CH2 | Yes | — | | | | 0.2 | .22 | .10 | 13 |
| Chloride | | | | | | | | | | | |
| | Control | D3 | No | 1.4 | 1.5 | 0.7 | 10 | 1.7 | 3.5 | 5.2 | 12 |
| | | D4 | No | 1.5 | 1.9 | 0.7 | 10 | 2.0 | 2.1 | 1.0 | 12 |
| | Test | CH1 | No | — | | | | 2.0 | 2.0 | 0.9 | 13 |
| | | CH1A | Yes | — | | | | 2.3 | 2.7 | 1.2 | 12 |
| | | CH2 | Yes | — | | | | 2.5 | 3.4 | 3.2 | 13 |
| Sulfate | | | | | | | | | | | |
| | Control | D3 | No | 2.0 | 1.9 | .8 | 10 | 2.1 | 2.4 | 1.2 | 12 |
| | | D4 | No | 2.2 | 2.3 | .8 | 10 | 2.1 | 2.1 | 0.3 | 12 |
| | Test | CH1 | No | — | | | | 2.1 | 2.1 | 0.4 | 13 |
| | | CH1A | Yes | — | | | | 2.1 | 2.1 | 0.3 | 12 |
| | | CH2 | Yes | — | | | | 1.9 | 2.1 | 0.6 | 13 |

## TABLE 40 (Cont'd)

| Parameter | Location | | Zinc | Phase I | | | | Phase II | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Median | Mean | S | N | Median | Mean | S | N |
| Nitrate-N | | | | | | | | | | | |
| | Control | D3 | No | 0.2 | .28 | .22 | 10 | 0.1 | 0.2 | 0.2 | 12 |
| | | D4 | No | 0.1 | .13 | .11 | 10 | 0.2 | 0.2 | 0.2 | 12 |
| | | CH1 | No | — | | | | 0.1 | 0.1 | 0.1 | 13 |
| | | CH1A | Yes | — | | | | 0.1 | 0.2 | 0.2 | 12 |
| | | CH2 | Yes | — | | | | 0.1 | 0.2 | 0.2 | 12 |
| TDS | | | | | | | | | | | |
| | Control | D3 | No | 15 | 16 | 4 | 10 | 26 | 28 | 12 | 12 |
| | | D4 | No | 18 | 20 | 5 | 10 | 25 | 28 | 7 | 12 |
| | Test | CH1 | No | — | | | | 27 | 25 | 5 | 13 |
| | | CH1A | Yes | — | | | | 25 | 27 | 6 | 12 |
| | | CH2 | Yes | — | | | | 30 | 31 | 8 | 13 |
| Hardness ($CaCO_3$) | | | | | | | | | | | |
| | Control | D3 | No | 8 | 9 | 3 | 10 | 11 | 12 | 3 | 12 |
| | | D4 | No | 11 | 12 | 3 | 10 | 13 | 13 | 2 | 12 |
| | Test | CH1 | No | — | | | | 12 | 13 | 3 | 13 |
| | | CH1A | Yes | — | | | | 12 | 13 | 2 | 12 |
| | | CH2 | Yes | — | | | | 14 | 15 | 2 | 13 |
| Manganese | | | | | | | | | | | |
| | Control | D3 | No | ND | .006 | .014 | 10 | ND | .003 | .007 | 12 |
| | | D4 | No | ND | .005 | .011 | 10 | ND | .005 | .008 | 12 |
| | Test | CH1 | No | — | | | | ND | ND | — | 12 |
| | | CH1A | Yes | — | | | | ND | .004 | .008 | 12 |
| | | CH2 | Yes | — | | | | ND | .007 | .019 | 13 |

## TABLE 40 (Cont'd)

| Parameter | Location | | Zinc | Phase I | | | | Phase II | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Median | Mean | S | N | Median | Mean | S | N |
| Amphibole (MFL) | | | | | | | | | | | |
| | Control | D3 | No | ND | .17 | .54 | 10 | ND | .008 | .029 | 12 |
| | | D4 | No | ND | .04 | .12 | 11 | ND | .048 | .144 | 12 |
| | Test | CH1 | No | — | | | | ND | .037 | .076 | 13 |
| | | CH1A | Yes | — | | | | ND | ND | — | 12 |
| | | CH2 | Yes | — | | | | ND | .042 | .111 | 13 |
| Langelier Index | | | | | | | | | | | |
| | Control | D3 | No | -5.0 | -4.8 | 0.6 | 10 | -2.2 | -2.0 | 0.5 | 10 |
| | | D4 | No | -3.6 | -3.6 | 0.4 | 10 | -0.8 | -0.8 | 0.4 | 10 |
| | Test | CH1 | No | — | | | | -1.8 | -1.8 | 0.5 | 10 |
| | | CH1A | Yes | — | | | | -1.6 | -1.6 | 0.4 | 9 |
| | | CH2 | Yes | — | | | | -1.1 | -1.0 | 0.4 | 10 |
| Zinc | | | | | | | | | | | |
| | Control | D3 | No | .039 | .055 | .049 | 10 | ND | .006 | .009 | 12 |
| | | D4 | No | .017 | .020 | .015 | 10 | ND | .004 | .014 | 12 |
| | Test | CH1 | No | — | | | | ND | .006 | .017 | 14 |
| | | CH1A | Yes | — | | | | 0.64 | .65 | .11 | 17 |
| | | CH2 | Yes | — | | | | 0.27 | .32 | .12 | 12 |
| Silica | | | | | | | | | | | |
| | Control | D3 | No | 5.5 | 5.9 | 1.3 | 10 | 5.3 | 5.4 | .35 | 12 |
| | | D4 | No | 6.1 | 6.4 | 0.9 | 10 | 5.7 | 5.7 | .31 | 12 |
| | Test | CH1 | No | — | | | | 5.5 | 5.6 | .53 | 13 |
| | | CH1A | Yes | — | | | | 5.4 | 5.4 | .33 | 12 |
| | | CH2 | Yes | — | | | | 5.3 | 5.3 | .36 | 13 |

## TABLE 40 (Cont'd)

| Parameter | Location | | Zinc | Phase I | | | | Phase II | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Median | Mean | S | N | Median | Mean | S | N |
| Fluoride | | | | | | | | | | | |
| | Control | D3 | No | 0.9 | .9 | .3 | 10 | 0.9 | 0.9 | 0.3 | 12 |
| | | D4 | No | 1.0 | 1.0 | .2 | 10 | 0.8 | 0.9 | 0.3 | 12 |
| | Test | CH1 | No | — | | | | 0.9 | 0.8 | 0.3 | 13 |
| | | CH1A | Yes | — | | | | 0.7 | 0.8 | 0.3 | 12 |
| | | CH2 | Yes | — | | | | 0.8 | 0.9 | 0.3 | 13 |
| Cl | | | | | | | | | | | |
| | Control | D3 | No | 0.3 | .3 | .3 | 10 | 0.5 | 0.5 | 0.2 | 11 |
| | | D4 | No | ND | .1 | .2 | 10 | ND | 0.1 | 0.2 | 11 |
| | Test | CH1 | No | — | | | | ND | 0.0 | 0.1 | 12 |
| | | CH1A | Yes | — | | | | ND | 0.0 | 0.1 | 11 |
| | | CH2 | Yes | — | | | | ND | ND | — | 12 |
| Temperature °C | | | | | | | | | | | |
| | Control | D3 | No | 11 | 10 | 3 | 10 | 9.0 | 10.1 | 3.6 | 10 |
| | | D4 | No | 13 | 13 | 4 | 10 | 12.5 | 12.4 | 4.3 | 11 |
| | Test | CH1 | No | — | | | | 10.5 | 10.8 | 3.7 | 12 |
| | | CH1A | Yes | — | | | | 8.3 | 11.0 | 3.8 | 11 |
| | | CH2 | Yes | — | | | | 12.0 | 13.5 | 4.4 | 12 |
| Dissolved Oxygen | | | | | | | | | | | |
| | Control | D3 | No | 11.3 | 10.7 | 2.4 | 11 | 12.0 | 12.1 | .5 | 3 |
| | | D4 | No | 10.5 | 10.6 | 1.6 | 11 | 11.8 | 12.0 | 1.1 | 3 |
| | Test | CH1 | No | — | | | | 11.3 | 12.0 | 1.0 | 4 |
| | | CH1A | Yes | — | | | | 11.5 | 12.4 | 0.9 | 3 |
| | | CH2 | Yes | — | | | | 11.4 | 11.6 | .7 | 4 |

## TABLE 40 (Cont'd)

| Parameter | Location | | Zinc | Phase I | | | | Phase II | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Median | Mean | S | N | Median | Mean | S | N |
| Sodium | | | | | | | | | | | |
| | Control | D3 | No | — | | | | 4.7 | 5.5 | 3.2 | 12 |
| | | D4 | No | — | | | | 4.2 | 4.6 | 0.6 | 12 |
| | Test | CH1 | No | — | | | | 4.4 | 4.4 | 0.3 | 12 |
| | | CH1A | Yes | — | | | | 4.3 | 4.5 | 0.4 | 12 |
| | | CH2 | Yes | — | | | | 4.3 | 4.7 | 1.5 | 12 |

# TABLE 41

## STATISTICAL COMPARISON OF CALCIUM PICKUP OVER THE CONTROL SECTION

| Phase I | | Phase II | | |
|---|---|---|---|---|
| Date | Calcium Increase | Date | Calcium Increase | |
| 4-2-81 | 1.90 | 4-26-83 | 1.70 | |
| 5-6-81 | 2.60 | 5-24-83 | .70 | |
| 6-3-81 | 1.20 | 6-21-83 | 1.50 | |
| 7-8-81 | 1.50 | 7-22-83 | 1.50 | |
| 8-5-81 | 1.50 | 8-23-83 | 1.50 | |
| 9-2-81 | 2.10 | 9-21-83 | 2.60 | |
| 10-7-81 | 1.80 | 10-18-83 | .40 | |
| 11-4-81 | 1.80 | 11-19-83 | 1.70 | |
| 1-8-82 | 1.10 | 12-15-83 | -1.60* | omitted |
| 3-3-82 | 1.20 | 1-21-84 | .70 | |
| | | 2-28-84 | 1.10 | |
| | | 4-2-84 | 1.10 | |

| | | | |
|---|---|---|---|
| Number of Samples (n) | = 10 | Number of Samples (n) | = 11 |
| Mean ($\bar{x}$) | = 1.67 | Mean ($\bar{x}$) | = 1.32 |
| Standard Deviation (s) | = 0.47 | Standard Deviation (s) | = 0.61 |

$$t = \cfrac{\bar{x}_1 - \bar{x}_2}{\sqrt{\cfrac{(n_1 - 1)S_1^2 + (n_2 - 1)S_2^2}{n_1 + n_2 - 2} \quad \cfrac{n_1 + n_2}{n_1 n_2}}}$$

Degrees of Freedom = 19 $\quad t = 1.46$

Conclusion: The difference between the two means is not significant.

## TABLE 42

## STATISTICAL COMPARISON OF SILICA PICKUP OVER THE CONTROL SECTION

| Phase I | | Phase II | |
|---|---|---|---|
| Date | Silica Increase | Date | Silica Increase |
| 4-2-81 | 0.4 | 4-26-83 | 0.4 |
| 5-6-81 | 0.5 | 5-24-83 | 0.4 |
| 6-3-81 | 1.0 | 6-21-83 | 0.4 |
| 7-8-81 | 0.4 | 7-22-83 | 0.1 |
| 8-5-81 | 0.9 | 8-23-83 | 0.4 |
| 9-2-81 | 0.4 | 9-21-83 | 0.7 |
| 10-7-81 | 0.5 | 10-18-83 | 0.3 |
| 11-4-81 | 1.2 | 11-19-83 | 0.1 |
| 1-8-82 | -0.4* omitted | 12-15-83 | -0.2* omitted |
| | | 1-21-84 | 0.0 |
| | | 2-28-84 | 0.3 |
| | | 4-2-84 | 0.3 |

| Phase I | | Phase II | |
|---|---|---|---|
| Number of Samples (n) | = 9 | Number of Samples (n) | = 11 |
| Mean ($\bar{x}$) | = 0.63 | Mean ($\bar{x}$) | = 0.31 |
| Standard Deviation (s) | = 0.31 | Standard Deviation (s) | = 0.61 |

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{(n_1 - 1)S_1^2 + (n_2 - 1)S_2^2}{n_1 + n_2 - 2} \quad \frac{n_1 + n_2}{n_1 n_2}}}$$

Degrees of Freedom = 18 $\quad$ t = 1.947

Conclusion: The difference between the two means is not significant.

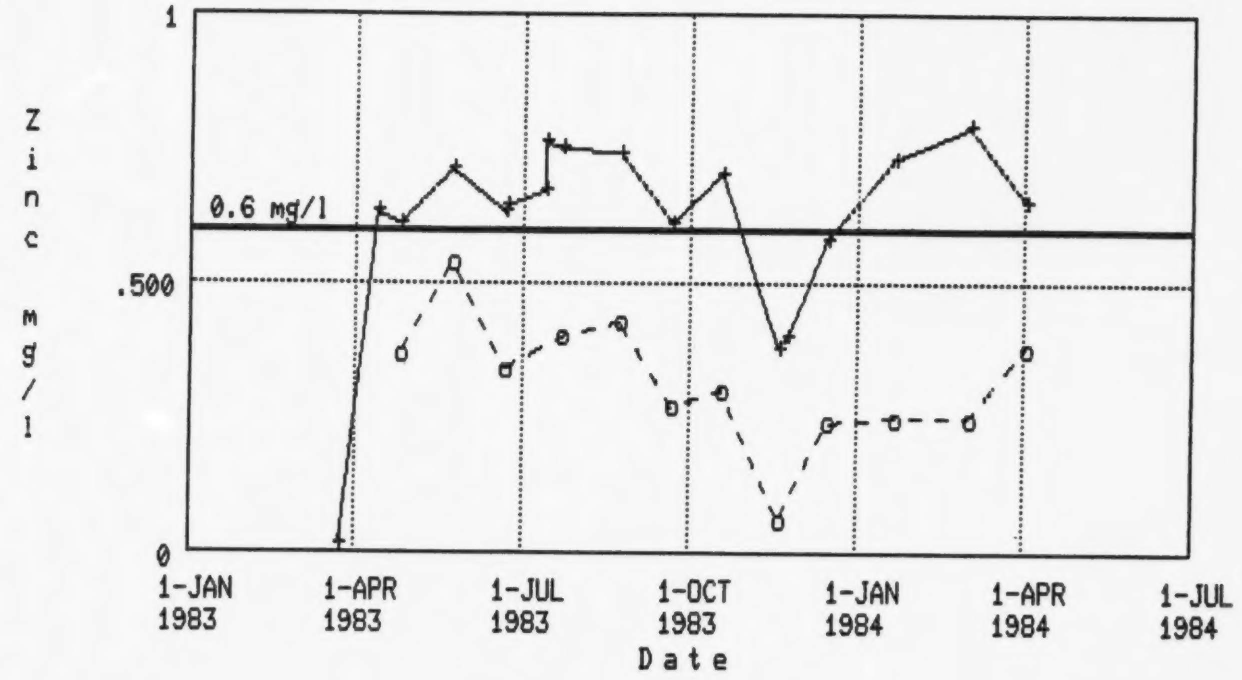
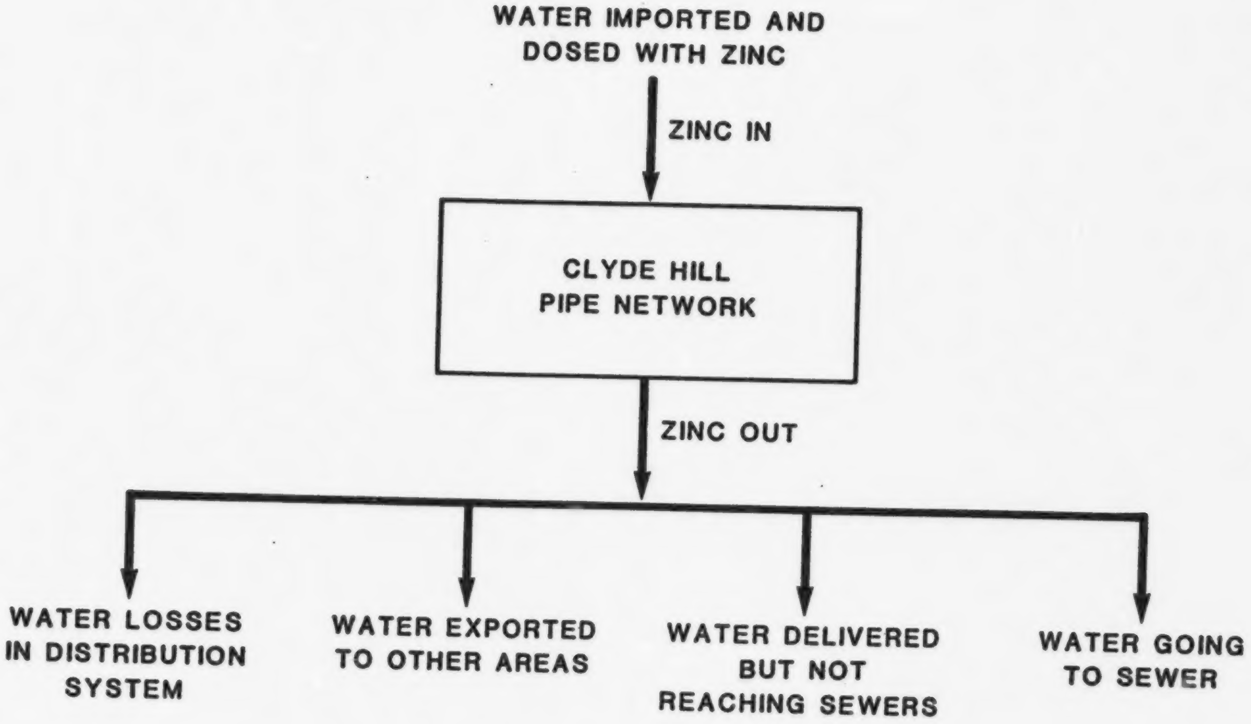


FIGURE 48

ZINC CONCENTRATIONS NEAR THE INJECTION POINT (CH1A)
AND AT THE END POINT (CH2)


WATER IMPORTED AND DOSED WITH ZINC
ZINC IN
CLYDE HILL PIPE NETWORK
ZINC OUT
WATER LOSSES IN DISTRIBUTION SYSTEM
WATER EXPORTED TO OTHER AREAS
WATER DELIVERED BUT NOT REACHING SEWERS
WATER GOING TO SEWER

(Zn ACCUMULATION) = (Zn IN) – (Zn OUT)

FIGURE 49

MASS BALANCE: ACCOUNTING FOR ZINC

## TABLE 43

## SUMMARY OF A ZINC MASS BALANCE FOR THE CLYDE HILL TEST AREA*

| | | |
|---|---|---|
| Zinc Input | | 233 kg |
| Zinc Output | | |
| Network Losses | 26 kg | |
| Zinc in Sewers | 107 kg | |
| Zinc in Consumed Water | 25 kg | |
| Total Output | 158 kg | 158 kg |
| Zinc Accumulation | | 75 kg |
| Fraction of Input | | 32% |

---

* Eleven full months of operation.

leakage. Second, 80 percent of the remaining water actually reaches the sewers themselves. Finally, it is assumed that twice as much water flows past S2 than S1, as indicated by Bellevue staff. However, since the concentrations in the two sewer sites are fairly similar, the differences between the assumed and actual flows do not significantly affect the end result.

There is evidence that both precipitation and deposition were occurring but the actual proportion of zinc going to one or the other could not be established. A comparison of zinc concentrations at the various sampling points is shown in Figure 50. At the dead-ends at CH3 and CH4, both soluble and total zinc samples were taken. The results at these two sites indicate that particulate zinc is forming. This indicates that if zinc addition is to be applied to the complete Bellevue system, flushing of dead-ends would be necessary at various intervals. Evidence that zinc may be forming a coating on the asbestos-cement pipes comes from X-ray analysis by the USEPA showing zinc on the surfaces of the A/C pipe sections placed and then removed from the field test sites. Zinc peaks are apparent in Figures 51 and 52 for CH1A and CH2, respectively; while they are not visible for A/C pipe located at D3 or on the unused pipe in Figures 53 and 54, respectively. The mortar lined A/C pipe behaved similarly to the A/C pipes in that zinc deposition was evident at CH1A and CH2, but not at D3. The interior surfaces of A/C pipes removed from D3 and D4 could be easily scratched with a fingernail. The interiors of A/C pipe from the CH1A and CH2 were harder to scratch, and unused A/C pipes could not be scratched at all. The dried interior of the A/C pipe removed from D3 and D4 showed loose clumps of fibers. These were not visible in the pipe removed from CH1A and CH2 or the unused pipe. This is further evidence of some protective action by the zinc.

A final consideration is the total amount of zinc being discharged into the Seattle sewage control system. Since the sewage effluent is discharged into the Green River, there is a 26 pound per day limit on the total amount of zinc in the discharge. Calculations from the test area show that the Clyde Hill area alone is putting about 0.32 kilograms (0.7 pounds) per day of zinc into the sewage lines. Applying zinc chloride to the entire Bellevue system, which has 50 times the flow of Clyde Hill, could influence the discharge if no zinc removal occurred in the plant. However, future zinc additions may be possible when the Seattle Effluent Transfer System is completed. This would be a new outfall at the bottom of Puget Sound which would bypass the Green River and go directly to Puget Sound, where this limit would not apply.

## Cost Comparison

A study of economics is necessary in order to gain a perspective on how zinc chloride treatment compares to other options available to water utilities which may have problems with deteriorating A/C pipe. The following cost comparison is purposely brief to give just a taste of the costs involved. A more detailed cost study is beyond the scope of this project.

A summary of the zinc chloride treatment costs is given in Table 44. The capital cost includes eight separate chemical feed stations determined on the simplifying assumption that Bellevue can be conveniently divided up as such. Other items includ a building to house the equipment, labor to build it, water meters, and metering pumps. The building is assumed to be built on land owned by Bellevue. Annual costs are divided

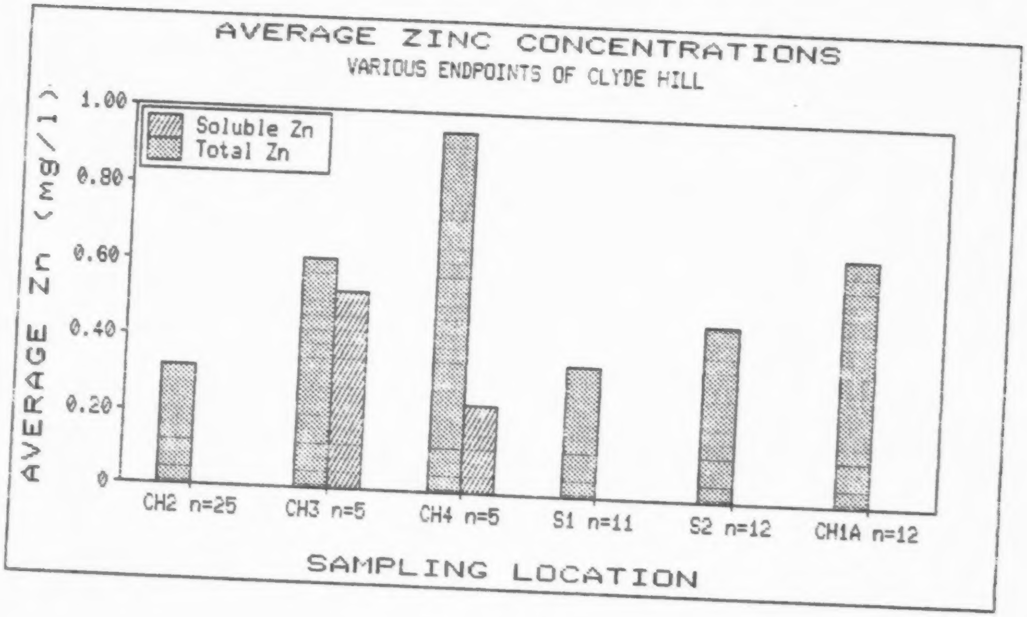


FIGURE 50

AVERAGE ZINC CONCENTRATIONS AT THE TEST AREA

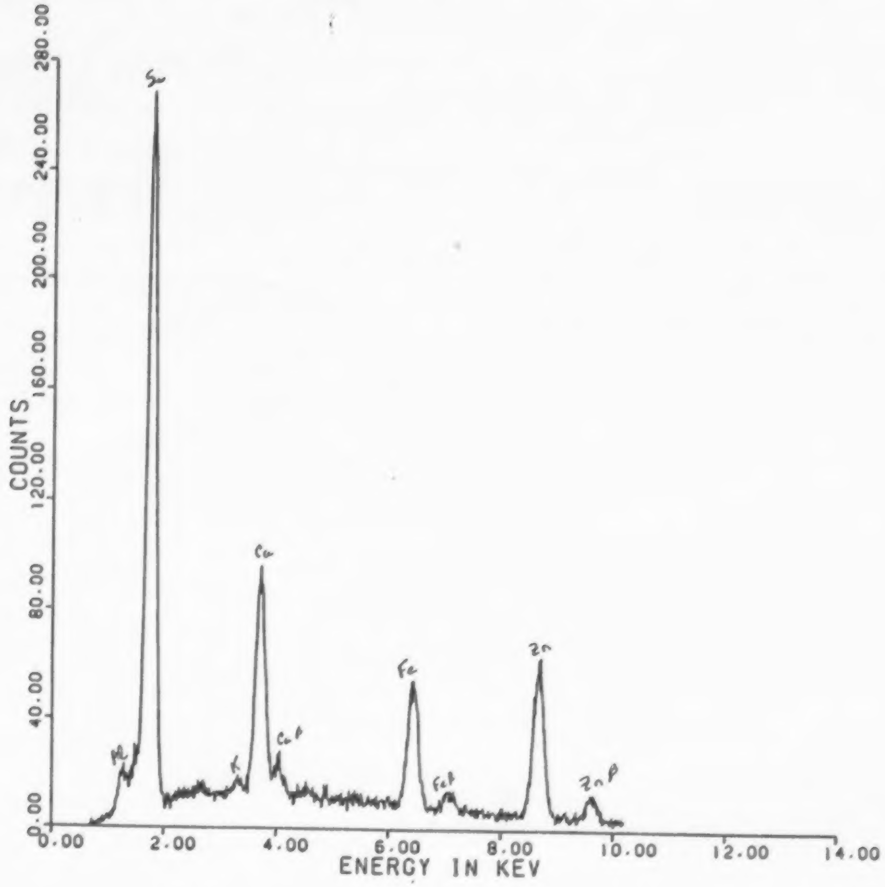


FIGURE 51

X-RAY SPECTRA OF A/C PIPE AT CH1A

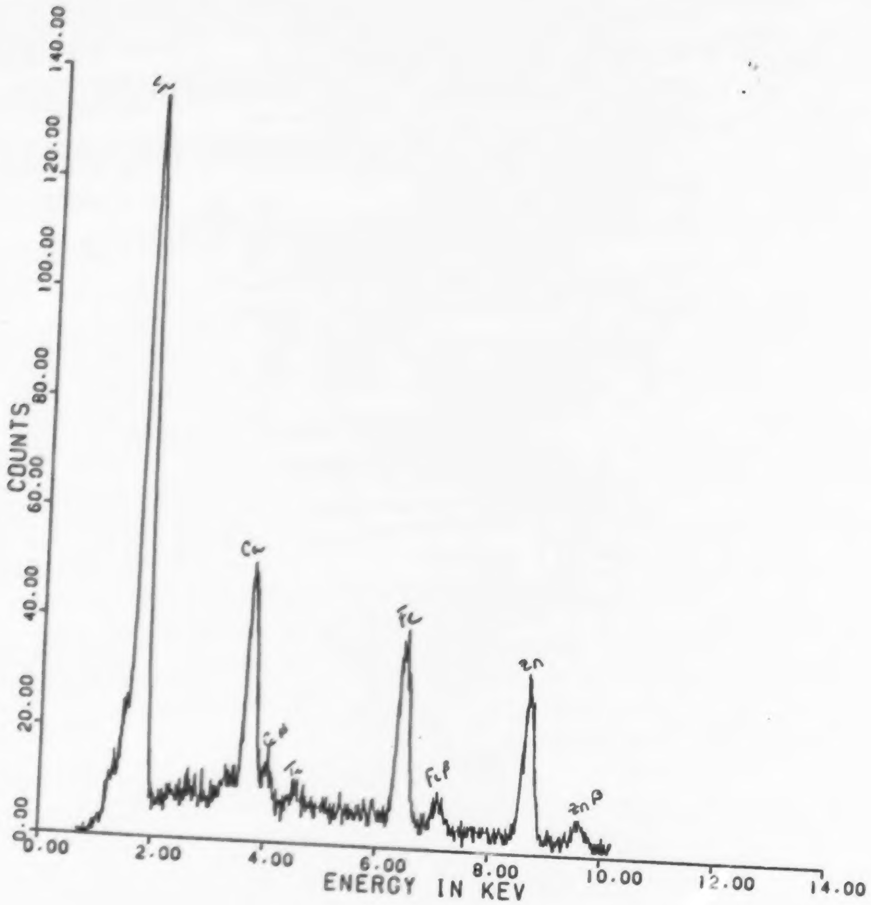


FIGURE 52

X-RAY SPECTRA OF A/C PIPE AT CH2

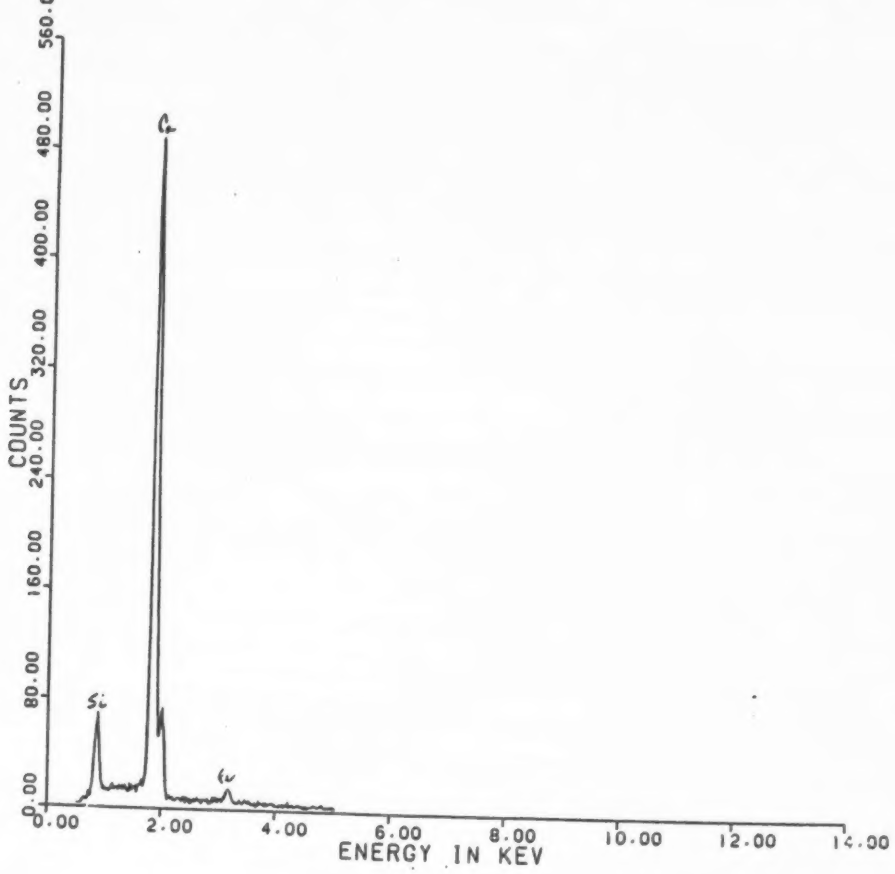


FIGURE 53
X-RAY SPECTRA OF UNUSED A/C PIPE

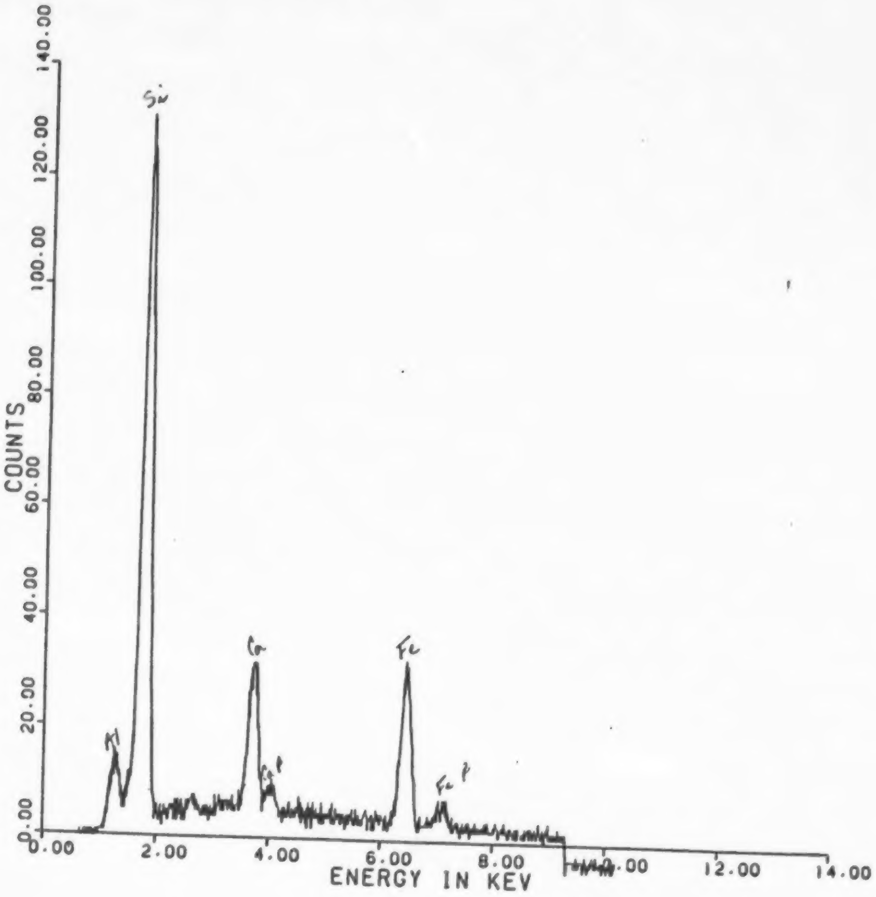


FIGURE 54

X-RAY SPECTRA OF A/C PIPE AT D3

# TABLE 44

# ZINC CHLORIDE TREATMENT COSTS

## DATA

Dose: 0.6 mg/L as zinc
Form of Zinc: Zinc chloride 50% (239,734 mg/L as zinc)
Total Bellevue Annual Flow: $20x10^{6}m^{3}$ ($5.5 \times 10^{9}$ gallons)

## COSTS

| | | |
|---|---|---|
| Capital Cost 8 Chemical Feed Stations (pumps, metering, storage structure) | | $244,000 |
| Annual Costs | | |
| Zinc Chloride | $22,300 | |
| O&M | $49,800 | |
| Total | $72,100 | |
| Equivalent Capital Cost (10%, perpetual) | | $721,000 |
| Total Present Value | | $965,000 |

into chemical costs for zinc chloride (about $12.25/100 lbs) and operations and maintenance costs which included labor, power, and replacement parts. Converting the annual cost to an equivalent present value gives a total present value of nearly $1 million.

Zinc orthophosphate is only available as a solid and costs 10 times more by weight than zinc chloride. For a solid, the chemical feed equipment would also be more expensive. In addition, the orthophosphate is not recommended in areas with open reservoirs because it is a nutrient.

Replacement and relining were considered since they represent the more conventional ways of dealing with pipe deterioration problems. The cost analysis is shown in Table 45. Replacing the A/C pipe with steel or ductile iron pipe is similar in cost, each totalling about $35.6 million. Both the steel and ductile iron pipe are assumed mortar lined and mortar coated. Replacement with PVC class 150 pipe costs about 10 percent less than steel and ductile iron; however, PVC pipe is only available up to 30 centimeters (12-inches) in diameter. For the larger diameters, steel pipe would be. All pipe replacement costs assumed two-meter (6 foot) cover and no allowance for service connections.

Relining consists of scraping the inside surface of the existing A/C pipe and then coating it with a mortar lining. Mortar lining can be accomplished down to a diameter of 10 centimeters (4-inches). The total cost is nearly $20 million or about 60 percent of the cost of replacing the A/C pipe as shown in Table 45.

Merely scraping or pigging the inner walls of the existing pipe proved to increase the amount of fibers released (EPA, March 1984) so it was not considered. Also, periodic flushing likewise produced higher fiber counts in the same study, so it was not considered in the cost comparison either.

Chemical treatment seems to be the least expensive measure for combating the pipe deterioration assuming it is effective. A more detailed planning and cost analysis would probably consider chemical treatment with phased replacement or phased relining of pipes in poor condition. Further zinc testing to prove its effectiveness would also be required.

## CONCLUSIONS

The following are conclusions drawn from the Phase II results:

1. It is difficult to determine with confidence whether the zinc chloride had any influence on the asbestos fiber release in the test section. Initial water quality tests indicated it reduced calcium, pH, and asbestos fiber increases in the test section, as opposed to control. However, water quality from control and test sections was more comparable after a year of the Seattle program.

2. The Seattle Corrosion Control Program probably had a significant effect on reducing the chrysotile fiber release in both the test area and the control

## TABLE 45

## A/C PIPE REPLACEMENT OR LINING COSTS

| Pipe Size | | Total Length | | Cost in $1000 | | | |
|---|---|---|---|---|---|---|---|
| cm | (inches) | meters | (feet) | Steel | Ductile Iron | PVC | Mortar Lining |
| 10 | 4 | 54,000 | 177,000 | 3,400 | 3,400 | 2,900 | 2,300 |
| 15 | 6 | 232,000 | 760,000 | 15,600 | 15,600 | 13,200 | 9,900 |
| 20 | 8 | 116,000 | 380,000 | 9,100 | 8,900 | 8,400 | 4,900 |
| 25 | 10 | 19,000 | 62,500 | 1,800 | 2,000 | 1,800 | 810 |
| 30 | 12 | 41,000 | 135,000 | 4,900 | 5,000 | 5,000 | 1,800 |
| 36 | 14 | 1,500 | 5,000 | 230 | 230 | 230* | 70 |
| 41 | 16 | 2,400 | 8,000 | 500 | 450 | 500* | 140 |
| 46 | 18 | 27 | 90 | -- | -- | -- | -- |
| 51 | 20 | 6 | 20 | -- | -- | -- | -- |
| 61 | 24 | 380 | 1,250 | 90 | 90 | 90* | 20 |
| Total Cost | | | | 35,620 | 35,670 | 32,120 | 19,940 |

* Using steel

area. Further monitoring to confirm this conclusion is recommended especially after several months of treatment.

3. Hardness testing was inconclusive in determining the effectiveness of the zinc chloride on actual A/C pipe placed in service over the one year field test.

4. Calcium loss measurements showed no difference in A/C pipe under test and control conditions, but visual and manual examination suggested pipe in the control section was softened.

5. Zinc accumulation as both particulates and coating on pipe walls in the test area does occur in the full scale application of zinc chloride. However, the proportion of zinc which ends up as particulate and that which ends up as coating on the A/C pipe is unclear.

6. A brief cost analysis shows chemical treatment to be the lowest cost alternative for dealing with A/C pipe deterioration. Therefore, further zinc chloride testing to prove its effectiveness is economically attractive.

# REFERENCES

Anderson and Long, "Interim Method for Determining Asbestos in Water," Report EPA-600/480-005, Cincinnati, Ohio (January 1980).

Buelow, R. W., Millette, J.R., McFarren, E.F., Symons, J.M., "The Behavior of Asbestos-Cement Pipe Under Various Water Quality Conditions: A Progress Report," JAWWA, 72:2:91 (February 1980).

Environmental Protection Agency, "Control of Asbestos Fiber Loss from Asbestos-Cement Watermain," Report Summary EPA-600/52-84-014, Cincinnati, Ohio (March 1984).

Environmental Protection Agency, "Quality Criteria for Water," Washington, D.C. (July 1976).

Hallenbeck, W., Chen, E., Hesse, C., Patel-Manklik, K., Wolfe, A., "Is Chrysotile Asbestos Released from Asbestos-Cement Pipe Into Drinking Water?," JAWWA, 70:2:97 (February 1978).

JMM, "Report on Snoqualmie River Water Supply Study," Report prepared for City of Bellevue, Washington (January 1978).

Kanarek, M.S., Conforti, P.M., Jackson, L.A., Cooper, R.C., Murchio, J.C., "Asbestos in Drinking Water and Cancer Incidence in the San Francisco Bay Area," Am. J. Eped. 1980, 112, 54.

Kanarek, M.S., Conforti, P.M., and Jackson, L.A., "Chrysotile Asbestos Fibers in Drinking Water from Asbestos Cement Pipe," Environ. Sci. and Tech. 15(8):923-925 (1981).

Kay, G.H., "Asbetos In Drinking Water," JAWWA; 66:9:513 (September 1974).

Kennedy Engineers, "Internal Corrosin Study, Phase 1 Report," City of Seattle (1976).

Kennedy Engineers, "Internal Corrosion Study, Phase 2 Report," City of Seattle (1978).

Langelier, W., "The Analytical Control of Anticorrosion Water Treatment," JAWWA, 28:1500 (1936).

Grubb, C., "Field Test of Corrosion Control to Protect Asbestos-Cement Pipe," EPA Report #EPA-600/2-81-023 (February 1981).

McCabe, L.J., Millette, J.R., "Health Effects and Prevalence of Asbestos Fibers in Drinking Water," Proceedings of AWWA Annual Conference, SAn Francisco, Califonria (June 1979).

Millette, J.R., Clark, P.J., and Pansing, M.F., "Exposure to Asbestos from Drinking Water in the United States," EPA-ORD Research Report # EPA 600/1-79-028 (1979).

Millette, James R., "Investigation of the Protective Effect of Iron Containing Coatings on Asbestos-Cement Pipe Exposed to Aggressive Water," Ph.D. Dissertation Submitted to the Department of Civil and Environmental Engineering, University of Cincinnati, Ohio (1983).

Millette, James R., et al., "Evaluating the Condition of Asbestos-Cement Pipe," Paper No. 152 presented at the Corrosion 84 Conference of the National Associatin of Corrosion Engineers (April 1984).

National Academy of Sciences; "Chemical Wuality of Water in the Distribution System," Chapter 3 of Drinking Water and Health, 1981.

Netzer, A. and Norman J.D., "Removal of Trace Metals from Water by Activated Carbon," Water Pollution Research in Canada, Vol. 8 (1973).

Olson, H.L., "Asbestos in Potable Water Supplies," JAWWA, 66:9:515 (September 1974).

Schock, M.R., Buelow, R.W., "The Behavior of Asbestos-Cement Pipe Under Various Water Quality Conditions: Part 2, Theoretical Considerations," JAWWA, 73:12:636 (December 1981).

Schock, M.R. "Temperature and Ionic Strength Corrections to the Langelier Index - Revisited," JAWWA 76:8:72 (August 1984).

Wright, G.W., "Some Comments on Dose-response Relationships for Other Malignant Asbestos-Related Diseases," Proc. of Asbestos Symposium, Glen, H.W. (ed) Johannesburg, SA, Oct., 1977. National Institute for Metalurgy, Randburg, SA, 95-105 (1978).

# APPENDIX A

## PHASE IA DATA

### GENERAL MINERALS FOR PHASE IA

D1: Cedar Inlet

| Date | pH | Alkalinity (CaCO3) | Calcium | Langelier Index | Zinc | Silica |
|---|---|---|---|---|---|---|
| 2-Apr-1981 | 7.1800 | 17.8000 | 6.7000 | -2.4500 | -6.0000 | 10.1000 |
| 6-May-1981 | 7.2000 | 16.1000 | 6.2000 | -2.4700 | 0.0140 | 10.3000 |
| 3-Jun-1981 | 7.4400 | 16.1000 | 6.2000 | -2.2000 | 0.0170 | 8.8000 |
| 8-Jul-1981 | 7.9100 | 17.0000 | 6.8000 | -1.5400 | -6.0000 | 11.0000 |
| 5-Aug-1981 | 8.7600 | 19.0000 | 8.4000 | -0.5300 | 0.1210 | 10.0000 |
| 2-Sep-1981 | 7.4000 | 22.0000 | 7.9000 | -1.8300 | 0.0190 | 9.9000 |
| 7-Oct-1981 | 5.8300 | 2.7000 | 2.9000 | -4.8700 | 0.0400 | 5.3000 |
| 4-Nov-1981 | 7.0300 | 18.0000 | 8.1000 | -2.4000 | 0.0290 | 9.9000 |
| 2-Dec-1981 | 5.7400 | -4.0000 | -4.0000 | -10.0000 | -4.0000 | -4.0000 |
| 8-Jan-1982 | 7.2700 | 9.6000 | 6.8000 | -2.6800 | 0.0150 | 8.8000 |
| 3-Mar-1982 | 6.7500 | 2.3000 | 5.8000 | -3.1400 | 0.0680 | 8.9000 |

-6 or -10 means 'NOT DETECTED'
-4 means 'NOT ANALYZED'

# GENERAL MINERALS FOR PHASE IA

| Date<br>D1: Cedar Inlet | Iron | Magnesium | Chloride | Sulfate | Nitrate | TDS |
|---|---|---|---|---|---|---|
| 2-Apr-1981 | -6.0000 | 1.4000 | 3.2000 | 0.9100 | 0.1800 | 40.0000 |
| 6-May-1981 | 0.0490 | 1.0000 | 2.7000 | 1.3000 | -6.0000 | 45.0000 |
| 3-Jun-1981 | 0.0300 | 1.0000 | 3.0000 | 2.4000 | 0.2000 | 21.0000 |
| 8-Jul-1981 | 0.0310 | 0.9000 | 1.5000 | 1.6000 | 0.1000 | 39.0000 |
| 5-Aug-1981 | 0.0460 | 1.0000 | 2.6000 | 1.8000 | -6.0000 | 38.0000 |
| 2-Sep-1981 | -6.0000 | 1.1000 | 2.0000 | 3.0000 | 0.1000 | 44.0000 |
| 7-Oct-1981 | 0.1700 | 0.2000 | 1.5000 | 2.5000 | 0.9000 | 14.0000 |
| 4-Nov-1981 | 0.1000 | 1.0000 | 3.3000 | 3.8000 | 0.3000 | 37.0000 |
| 2-Dec-1981 | -4.0000 | -4.0000 | -4.0000 | -4.0000 | -4.0000 | -4.0000 |
| 8-Jan-1982 | 0.0420 | 0.9000 | 2.2000 | 1.5000 | 0.1000 | 29.0000 |
| 3-Mar-1982 | 0.0580 | 0.9000 | 2.7000 | 2.0000 | 0.2000 | 27.0000 |

-6 or -10 means 'NOT DETECTED'
-4 means 'NOT ANALYZED'

## GENERAL MINERALS FOR PHASE IA

D1: Cedar Inlet

| Date | Hardness (CaCO3) | Manganese | Fluoride | Free Chlorine | Temperature C | Dissolved Oxygen |
|---|---|---|---|---|---|---|
| 2-Apr-1981 | 22.5000 | - 6.0000 | 0.9800 | - 4.0000 | 9.5000 | 12.2000 |
| 6-May-1981 | 19.0000 | 0.0230 | 1.1000 | 0.3000 | 11.0000 | 11.3000 |
| 3-Jun-1981 | 20.0000 | - 6.0000 | 1.0000 | 0.4000 | 12.0000 | 10.7000 |
| 8-Jul-1981 | 21.0000 | - 6.0000 | 0.9000 | 0.2000 | 17.0000 | 7.8000 |
| 5-Aug-1981 | 25.0000 | - 6.0000 | 1.0000 | - 6.0000 | 18.0000 | 10.1000 |
| 2-Sep-1981 | 24.0000 | - 6.0000 | 0.7000 | 0.7000 | 19.0000 | 9.8000 |
| 7-Oct-1981 | 8.0000 | - 6.0000 | 0.5000 | 0.4000 | 14.0000 | 14.2000 |
| 4-Nov-1981 | 24.0000 | - 6.0000 | 1.5000 | 0.6000 | 14.0000 | 12.2000 |
| 2-Dec-1981 | - 4.0000 | - 4.0000 | - 4.0000 | - 6.0000 | 9.0000 | 10.6000 |
| 8-Jan-1982 | 21.0000 | 0.0130 | 0.9000 | 0.4000 | 7.0000 | 5.9000 |
| 3-Mar-1982 | 18.0000 | - 6.0000 | 0.6000 | 0.9000 | 8.0000 | 13.6000 |

-6 or -10 means 'NOT DETECTED'
-4 means 'NOT ANALYZED'

## GENERAL MINERALS FOR PHASE IA

| Date | pH | Alkalinity (CaCO3) | Calcium | Langelier Index | Zinc | Silica |
|---|---|---|---|---|---|---|
| D2: Cedar Outlet | | | | | | |
| 2-Apr-1981 | 7.9500 | 18.8000 | 7.4000 | -1.5900 | 0.0400 | 10.2000 |
| 6-May-1981 | 8.4500 | 16.6000 | 7.4000 | -1.0800 | 0.0090 | 10.1000 |
| 3-Jun-1981 | 8.8400 | 19.9000 | 7.5000 | -0.5800 | 0.0360 | 9.0000 |
| 8-Jul-1981 | 8.7600 | 23.0000 | 7.8000 | -0.4800 | -6.0000 | 11.0000 |
| 5-Aug-1981 | 8.5400 | 25.0000 | 8.8000 | -0.5300 | 0.0510 | 11.0000 |
| 2-Sep-1981 | 8.8300 | 26.0000 | 10.0000 | -0.1500 | 0.0230 | 10.0000 |
| 7-Oct-1981 | 6.9200 | 7.3000 | 4.7000 | -3.0600 | 0.1800 | 5.4000 |
| 4-Nov-1981 | 8.0300 | 20.0000 | 9.7000 | -1.2700 | 0.0160 | 10.0000 |
| 2-Dec-1981 | 6.5800 | -4.0000 | -4.0000 | -10.0000 | -4.0000 | -4.0000 |
| 8-Jan-1982 | 7.4700 | 16.2000 | 6.9000 | -2.2500 | 0.0130 | 9.0000 |
| 3-Mar-1982 | 7.4700 | 14.5000 | 7.4000 | -2.2400 | -6.0000 | 9.6000 |

-6 or -10 means 'NOT DETECTED'
-4 means 'NOT ANALYZED'

## GENERAL MINERALS FOR PHASE IA

D2: Cedar Outlet

| Date | Iron | Magnesium | Chloride | Sulfate | Nitrate | TDS |
|---|---|---|---|---|---|---|
| 2-Apr-1981 | 0.0400 | 1.3000 | 2.8000 | 0.5600 | 0.1700 | 44.0000 |
| 6-May-1981 | 0.0390 | 0.0180 | 2.3000 | 1.7000 | -6.0000 | 48.0000 |
| 3-Jun-1981 | 0.0680 | 0.8000 | 3.0000 | 2.0000 | 0.1000 | 28.0000 |
| 8-Jul-1981 | -6.0000 | 1.8000 | 1.7000 | 1.4000 | 0.1000 | 42.0000 |
| 5-Aug-1981 | 0.0340 | 0.8000 | 2.0000 | 1.8000 | -6.0000 | 36.0000 |
| 2-Sep-1981 | -6.0000 | 0.9000 | 2.0000 | 2.0000 | 0.1000 | 43.0000 |
| 7-Oct-1981 | 0.1100 | 0.2000 | 1.8000 | 2.3000 | 0.6000 | 18.0000 |
| 4-Nov-1981 | 0.0470 | 0.8000 | 2.9000 | 2.8000 | 0.2000 | 33.0000 |
| 2-Dec-1981 | -4.0000 | -4.0000 | -4.0000 | -4.0000 | -4.0000 | -4.0000 |
| 8-Jan-1982 | 0.0680 | 0.9000 | 1.4000 | 1.1000 | -6.0000 | 35.0000 |
| 3-Mar-1982 | 0.0810 | 0.8000 | 2.9000 | 2.4000 | 0.2000 | 31.0000 |

-6 or -10 means 'NOT DETECTED'
-4 means 'NOT ANALYZED'

## GENERAL MINERALS FOR PHASE IA

D2: Cedar Outlet

| Date | Hardness (CaCO3) | Manganese | Fluoride | Free Chlorine | Temperature C | Dissolved Oxygen |
|---|---|---|---|---|---|---|
| 2-Apr-1981 | 23.8000 | - 6.0000 | 1.0300 | - 4.0000 | 10.5000 | 11.3000 |
| 6-May-1981 | 22.0000 | 0.0180 | 1.1000 | 0.2000 | 13.0000 | 10.6000 |
| 3-Jun-1981 | 22.0000 | 0.0120 | 1.0000 | 0.4000 | 14.0000 | 10.4000 |
| 8-Jul-1981 | 23.0000 | - 6.0000 | 0.9000 | - 6.0000 | 18.0000 | 6.6000 |
| 5-Aug-1981 | 25.0000 | - 6.0000 | 1.1000 | - 6.0000 | 21.0000 | 10.5000 |
| 2-Sep-1981 | 29.0000 | - 6.0000 | 0.6000 | 0.5000 | 22.0000 | 8.9000 |
| 7-Oct-1981 | 13.0000 | - 6.0000 | 0.6000 | 0.2000 | 17.0000 | 14.0000 |
| 4-Nov-1981 | 27.0000 | 0.0140 | 1.3000 | 0.5000 | 14.0000 | 10.8000 |
| 2-Dec-1981 | - 4.0000 | - 4.0000 | - 4.0000 | 0.4000 | 11.0000 | 10.6000 |
| 8-Jan-1982 | 21.0000 | 0.0210 | 0.5000 | 0.4000 | 7.0000 | 7.1000 |
| 3-Mar-1982 | 22.0000 | - 6.0000 | 0.8000 | 0.6000 | 8.0000 | 13.8000 |

-6 or -10 means 'NOT DETECTED'
-4 means 'NOT ANALYZED'

# GENERAL MINERALS FOR PHASE IA

D3: Tolt Inlet

| Date | pH | Alkalinity (CaCO3) | Calcium | Langelier Index | Zinc | Silica |
|---|---|---|---|---|---|---|
| 2-Apr-1981 | 5.6000 | 6.9000 | 2.2000 | -4.9700 | 0.0400 | 6.0000 |
| 6-May-1981 | 5.6000 | 11.8000 | 2.1000 | -4.7200 | 0.0690 | 6.0000 |
| 3-Jun-1981 | 5.7800 | 2.6000 | 2.4000 | -5.0800 | 0.0380 | 5.3000 |
| 8-Jul-1981 | 5.7300 | 8.3000 | 2.6000 | -4.5500 | 0.0320 | 5.5000 |
| 5-Aug-1981 | 5.7700 | 5.0000 | 2.4000 | -4.7400 | 0.1900 | 5.7000 |
| 2-Sep-1981 | 5.5000 | 4.0000 | 2.4000 | -5.0800 | 0.0390 | 5.4000 |
| 7-Oct-1981 | 5.7700 | 2.3000 | 2.5000 | -5.0600 | 0.0450 | 5.2000 |
| 4-Nov-1981 | 5.4500 | 1.9000 | 2.7000 | -5.5100 | 0.0500 | 5.5000 |
| 8-Jan-1982 | 6.1000 | 2.7000 | 2.5000 | -4.8900 | 0.0250 | 4.8000 |
| 3-Mar-1982 | 6.6700 | 12.7000 | 5.7000 | -3.2400 | 0.0200 | 9.3000 |

-6 or -10 means 'NOT DETECTED'
-4 means 'NOT ANALYZED'

## GENERAL MINERALS FOR PHASE IA

D3: Tolt Inlet

| Date | Iron | Magnesium | Chloride | Sulfate | Nitrate | TDS |
|---|---|---|---|---|---|---|
| 2-Apr-1981 | 0.0500 | 1.1000 | 1.0000 | 0.6200 | 0.1700 | 16.0000 |
| 6-May-1981 | 0.0850 | 0.4000 | 1.9000 | 2.5000 | -6.0000 | 15.0000 |
| 3-Jun-1981 | 0.0560 | 0.5000 | 2.1000 | 2.2000 | 0.2000 | 10.0000 |
| 8-Jul-1981 | 0.0370 | 0.6000 | 1.1000 | 2.3000 | 0.2000 | 18.0000 |
| 5-Aug-1981 | 0.0750 | 0.4000 | 0.9000 | 1.9000 | 0.2000 | 14.0000 |
| 2-Sep-1981 | 0.0500 | 0.4000 | 1.5000 | 2.0000 | 0.2000 | 15.0000 |
| 7-Oct-1981 | 0.1400 | 0.3000 | 1.4000 | 2.8000 | 0.8000 | 15.0000 |
| 4-Nov-1981 | 0.1200 | 0.4000 | 2.1000 | 2.9000 | 0.2000 | 14.0000 |
| 8-Jan-1982 | 0.1800 | 0.4000 | 0.4000 | 0.4000 | -6.0000 | 13.0000 |
| 3-Mar-1982 | 0.0460 | 0.9000 | 2.9000 | 1.8000 | 0.2000 | 26.0000 |

-6 or -10 means 'NOT DETECTED'
-4 means 'NOT ANALYZED'

## GENERAL MINERALS FOR PHASE IA

| Date | Hardness (CaCO3) | Manganese | Fluoride | Free Chlorine | Temperature C | Dissolved Oxygen |
|---|---|---|---|---|---|---|
| D3: Tolt Inlet | | | | | | |
| 2-Apr-1981 | 10.0000 | - 6.0000 | 1.1800 | - 4.0000 | 7.5000 | 11.6000 |
| 6-May-1981 | 7.0000 | - 6.0000 | 1.2000 | 0.5000 | 9.0000 | 10.1000 |
| 3-Jun-1981 | 8.0000 | - 6.0000 | 0.8000 | 0.1000 | 11.5000 | 10.7000 |
| 8-Jul-1981 | 9.0000 | - 6.0000 | 1.1000 | - 6.0000 | 13.0000 | 6.0000 |
| 5-Aug-1981 | 8.0000 | - 6.0000 | 0.8000 | - 6.0000 | 14.0000 | 11.3000 |
| 2-Sep-1981 | 8.0000 | - 6.0000 | 0.6000 | - 6.0000 | 15.0000 | 9.1000 |
| 7-Oct-1981 | 7.0000 | - 6.0000 | 1.2000 | 0.6000 | 14.0000 | 14.5000 |
| 4-Nov-1981 | 8.0000 | 0.0240 | 1.1000 | 0.3000 | 11.0000 | 11.6000 |
| 2-Dec-1981 | - 4.0000 | - 4.0000 | - 4.0000 | 0.6000 | - 4.0000 | 12.5000 |
| 8-Jan-1982 | 8.0000 | 0.0390 | 0.3000 | 0.3000 | 5.0000 | 7.5000 |
| 3-Mar-1982 | 18.0000 | - 6.0000 | 0.9000 | 0.9000 | 7.0000 | 12.4000 |

-6 or -10 means 'NOT DETECTED'
-4 means 'NOT ANALYZED'

# GENERAL MINERALS FOR PHASE IA

D4: Tolt Outlet

| Date | pH | Alkalinity (CaCO3) | Calcium | Langelier Index | Zinc | Silica |
|---|---|---|---|---|---|---|
| 2-Apr-1981 | 6.5000 | 8.3000 | 4.1000 | - 3.6900 | 0.0100 | 6.4000 |
| 6-May-1981 | 6.6100 | 9.6000 | 4.7000 | - 3.3700 | - 6.0000 | 6.5000 |
| 3-Jun-1981 | 6.4000 | 6.2000 | 3.6000 | - 3.8200 | 0.0310 | 5.7000 |
| 8-Jul-1981 | 6.5400 | 8.0000 | 4.1000 | - 3.5000 | 0.0420 | 6.5000 |
| 5-Aug-1981 | 6.4600 | 8.0000 | 3.9000 | - 3.6200 | 0.0440 | 6.1000 |
| 2-Sep-1981 | 6.3200 | 7.0000 | 4.5000 | - 3.6200 | 0.0200 | 6.3000 |
| 7-Oct-1981 | 6.4800 | 6.4000 | 4.3000 | - 3.6200 | 0.0170 | 5.6000 |
| 4-Nov-1981 | 6.1100 | 5.1000 | 4.5000 | - 4.1500 | 0.0250 | 6.0000 |
| 8-Jan-1982 | 6.5800 | 4.0000 | 3.6000 | - 4.0500 | - 6.0000 | 6.0000 |
| 3-Mar-1982 | 7.0200 | 13.5000 | 6.9000 | - 2.7500 | 0.0150 | 8.9000 |

-6 or -10 means 'NOT DETECTED'
-4 means 'NOT ANALYZED'

GENERAL MINERALS FOR PHASE IA

D4: Tolt Outlet

| Date | Iron | Magnesium | Chloride | Sulfate | Nitrate | TDS |
|---|---|---|---|---|---|---|
| 2-Apr-1981 | 0.1100 | 1.1000 | 2.4000 | 0.7600 | 0.1700 | 20.0000 |
| 6-May-1981 | 0.0780 | 0.4000 | 2.3000 | 2.4000 | -6.0000 | 28.0000 |
| 3-Jun-1981 | 0.0810 | 0.4000 | 2.0000 | 1.9000 | 0.1000 | 16.0000 |
| 8-Jul-1981 | 0.1700 | 0.2000 | 1.5000 | 1.8000 | 0.1000 | 18.0000 |
| 5-Aug-1981 | 0.0740 | 0.2000 | 0.9000 | 2.1000 | -6.0000 | 16.0000 |
| 2-Sep-1981 | 0.0800 | 0.2000 | 2.0000 | 3.0000 | 0.1000 | 19.0000 |
| 7-Oct-1981 | 0.1600 | -6.0000 | 1.4000 | 2.8000 | 0.4000 | 19.0000 |
| 4-Nov-1981 | 0.1100 | 0.2000 | 1.5000 | 3.6000 | 0.1000 | 16.0000 |
| 8-Jan-1982 | 0.1200 | 0.3000 | 1.5000 | 2.2000 | 0.1000 | 14.0000 |
| 3-Mar-1982 | 0.0540 | 0.5000 | 3.2000 | 2.3000 | 0.2000 | 29.0000 |

-6 or -10 means 'NOT DETECTED'
-4 means 'NOT ANALYZED'

## GENERAL MINERALS FOR PHASE IA

D4: Tolt Outlet

| Date | Hardness (CaCO3) | Manganese | Fluoride | Free Chlorine | Temperature C | Dissolved Oxygen |
|---|---|---|---|---|---|---|
| 2-Apr-1981 | 14.7000 | 0.0300 | 1.2000 | -4.0000 | 9.0000 | 11.3000 |
| 6-May-1981 | 13.0000 | -6.0000 | 1.2000 | -6.0000 | 12.5000 | 10.0000 |
| 3-Jun-1981 | 11.0000 | -6.0000 | 1.1000 | -6.0000 | 15.0000 | 10.4000 |
| 8-Jul-1981 | 11.0000 | -6.0000 | 1.1000 | -6.0000 | 18.0000 | 7.3000 |
| 5-Aug-1981 | 11.0000 | -6.0000 | 0.8000 | -6.0000 | 14.5000 | 10.5000 |
| 2-Sep-1981 | 12.0000 | -6.0000 | 0.7000 | -6.0000 | 20.0000 | 8.6000 |
| 7-Oct-1981 | 11.0000 | -6.0000 | 0.8000 | 0.2000 | 16.0000 | 12.6000 |
| 4-Nov-1981 | 12.0000 | -6.0000 | 1.0000 | -6.0000 | 13.0000 | 10.3000 |
| 2-Dec-1981 | -4.0000 | -4.0000 | -4.0000 | 0.2000 | -4.0000 | 13.0000 |
| 8-Jan-1982 | 10.0000 | 0.0190 | 1.0000 | 0.1000 | 6.0000 | 10.6000 |
| 3-Mar-1982 | 19.0000 | -6.0000 | 0.9000 | 0.5000 | 8.0000 | 11.8000 |

-6 or -10 means 'NOT DETECTED'
-4 means 'NOT ANALYZED'

# APPENDIX B

## PHASE IB DATA

### GENERAL MINERALS FOR PHASE IB

T1: Cedar Control

| Week | pH | Alkalinity | Calcium | Langelier Index | Zinc | Silica |
|---|---|---|---|---|---|---|
| 0 | 7.3000 | 17.0000 | 6.9000 | -2.2000 | 0.0090 | 10.0000 |
| 1 | 7.5900 | 17.7000 | 7.3000 | -1.7000 | 0.0140 | 9.8000 |
| 2 | 7.0300 | 18.8000 | 6.0000 | -2.3000 | -6.0000 | 14.0000 |
| 3 | 7.0300 | 19.6000 | 6.8000 | -2.3000 | 0.0160 | 10.0000 |
| 4 | 6.9800 | 18.7000 | 7.5000 | -2.3000 | -6.0000 | 10.0000 |
| 5 | 6.9600 | 22.1000 | 7.8000 | -2.2000 | 0.0260 | 10.5000 |
| 6 | 7.0600 | 27.2000 | 8.4000 | -2.0000 | 0.0130 | 11.0000 |
| 7 | 7.2300 | 23.6000 | 7.0000 | -1.9000 | 0.0340 | 10.1000 |
| 8 | 7.3000 | 25.0000 | 7.2000 | -1.8000 | 0.0210 | 10.9000 |
| 9 | 7.4200 | 24.0000 | 8.8000 | -1.6000 | 0.0250 | 11.7000 |
| 10 | 7.4700 | 28.9000 | 9.1000 | -1.5000 | 0.0370 | 11.2000 |
| 11 | 7.4900 | 26.3000 | 8.2000 | -1.5000 | 0.0340 | 11.6000 |
| 12 | 7.5600 | 28.6000 | 8.5000 | -1.4000 | 0.0590 | 12.4000 |
| 16 | 7.8100 | 28.0000 | 9.9000 | -1.0000 | 0.0240 | 12.0000 |
| 20 | 7.9900 | 28.0000 | 9.5000 | -1.0000 | 0.0210 | 12.0000 |
| 24 | 7.9900 | 30.0000 | 11.0000 | -0.9000 | 0.0610 | 13.0000 |
| 28 | 8.0500 | 29.0000 | 11.0000 | -0.9000 | 0.0950 | 14.0000 |
| 32 | 8.1100 | 25.0000 | 11.0000 | -0.9000 | 0.0490 | 12.2000 |
| 36 | 8.1400 | -4.0000 | -4.0000 | -4.0000 | -4.0000 | -4.0000 |
| 40 | 7.8900 | 31.0000 | 10.8000 | -1.1000 | 0.0200 | 12.8000 |
| 44 | 7.8600 | -4.0000 | -4.0000 | -4.0000 | -4.0000 | -4.0000 |
| 48 | 7.8500 | 26.0000 | 10.8000 | -1.2000 | 0.0590 | 14.4000 |

-6 or -10 means 'NOT DETECTED'
-4 means 'NOT ANALYZED'

### GENERAL MINERALS FOR PHASE IB

T1: Cedar Control

| Week | Iron | Magnesium | Chloride | Sulfate | Nitrate | TDS |
|---|---|---|---|---|---|---|
| 0 | 0.0300 | 1.7000 | 3.9000 | 1.9000 | 8.0600 | 39.0000 |
| 1 | 0.1000 | 1.0000 | 3.9000 | 1.6000 | 0.1000 | 46.0000 |
| 2 | -6.0000 | 1.2000 | 3.9000 | -6.0000 | 0.1000 | 49.0000 |
| 3 | 0.0580 | 1.0000 | 4.4000 | 1.6000 | -6.0000 | 59.0000 |
| 4 | -6.0000 | 0.9000 | 3.8000 | 4.3000 | -6.0000 | 50.0000 |
| 5 | 0.0400 | 1.1000 | 5.9000 | -6.0000 | 0.4000 | 33.0000 |
| 6 | 0.0400 | 0.9000 | 9.0000 | 0.1000 | 0.0100 | 43.0000 |
| 7 | 0.0620 | 0.9000 | 9.2000 | 3.0000 | 0.1000 | 48.0000 |
| 8 | 0.0300 | 0.9000 | 9.5000 | -6.0000 | -6.0000 | 33.0000 |
| 9 | 0.0390 | 1.0000 | 10.9000 | 2.0000 | -6.0000 | 65.0000 |
| 10 | 0.0240 | 0.8000 | 10.5000 | 2.1000 | 0.0400 | 48.0000 |
| 11 | 0.0420 | 0.8000 | 8.8000 | 1.8000 | -6.0000 | 45.0000 |
| 12 | 0.0720 | 0.9000 | 10.4000 | 1.9000 | 0.1000 | 52.0000 |
| 16 | 0.0370 | 0.9000 | 14.0000 | 2.2000 | 0.1000 | 76.0000 |
| 20 | 0.0400 | 0.8000 | 16.0000 | 2.0000 | 0.1000 | 65.0000 |
| 24 | 0.2000 | 0.7000 | 14.0000 | 2.9000 | -6.0000 | 67.0000 |
| 28 | 3.3400 | 0.9000 | 15.0000 | 2.8000 | 0.1000 | 71.0000 |
| 32 | 0.1300 | 0.9000 | 18.0000 | 2.2000 | 0.1000 | 75.0000 |
| 36 | -4.0000 | -4.0000 | -4.0000 | -4.0000 | -4.0000 | -4.0000 |
| 40 | 0.0310 | 0.8000 | 17.0000 | 2.7000 | -6.0000 | 72.0000 |
| 44 | -4.0000 | -4.0000 | -4.0000 | -4.0000 | -4.0000 | -4.0000 |
| 48 | 0.0350 | 0.7000 | 20.0000 | 2.8000 | 0.1000 | 79.0000 |

-6 or -10 means 'NOT DETECTED'
-4 means 'NOT ANALYZED'

## GENERAL MINERALS FOR PHASE IB

T1: Cedar Control

| Week | Hardness (CaCO3) | Manganese | Fluoride | Free Chlorine | Temperature C | Dissolved Oxygen |
|---|---|---|---|---|---|---|
| 0 | 24.2000 | -6.0000 | 1.0000 | -4.0000 | 15.0000 | 11.2000 |
| 1 | 22.3000 | 0.0100 | 0.9000 | -4.0000 | 20.0000 | 10.1000 |
| 2 | 20.0000 | 0.0300 | 0.9000 | -6.0000 | 21.0000 | 7.1500 |
| 3 | 19.0000 | 0.0720 | 0.9000 | -6.0000 | 21.0000 | 5.5000 |
| 4 | 23.0000 | 0.0120 | 1.1000 | -6.0000 | 21.0000 | 4.0000 |
| 5 | 24.0000 | -6.0000 | 1.0000 | -6.0000 | 21.0000 | 3.0000 |
| 6 | 23.0000 | -6.0000 | 0.9000 | -6.0000 | 23.0000 | 2.3000 |
| 7 | 21.0000 | -6.0000 | 1.1000 | 1.7000 | 23.0000 | 2.8000 |
| 8 | 22.0000 | -6.0000 | 1.0000 | 0.6000 | 22.0000 | 2.9500 |
| 9 | 26.0000 | -6.0000 | 0.5000 | 1.0000 | 24.0000 | 3.1000 |
| 10 | 26.0000 | -6.0000 | 0.9000 | 1.1000 | 22.5000 | 3.8000 |
| 11 | 24.0000 | -6.0000 | 0.9000 | 1.3000 | 25.0000 | 4.4000 |
| 12 | 25.0000 | -6.0000 | 0.9000 | 0.5000 | 24.0000 | 4.4000 |
| 16 | 28.0000 | -6.0000 | 0.6000 | 5.6000 | 26.0000 | 5.6000 |
| 20 | 27.0000 | -6.0000 | 1.0000 | 1.0000 | 23.0000 | 5.9000 |
| 24 | 31.0000 | -6.0000 | 0.6000 | 0.6000 | 22.0000 | 6.3000 |
| 28 | 31.0000 | -6.0000 | 1.1000 | 5.9000 | 20.0000 | 6.7500 |
| 32 | 31.0000 | -6.0000 | 1.3000 | 1.4000 | 18.5000 | 8.8000 |
| 36 | -4.0000 | -4.0000 | -4.0000 | 0.8000 | 19.0000 | 8.2000 |
| 40 | 30.0000 | 0.0330 | 1.1000 | 0.7000 | 19.0000 | 8.9000 |
| 44 | -4.0000 | -4.0000 | -4.0000 | 1.1000 | 21.0000 | 8.7000 |
| 48 | 30.0000 | -6.0000 | 1.2000 | 1.0000 | 17.0000 | 10.2000 |

-6 or -10 means 'NOT DETECTED'
-4 means 'NOT ANALYZED'

## GENERAL MINERALS FOR PHASE IB

T2: Tolt Control

| Week | pH | Alkalinity | Calcium | Langelier Index | Zinc | Silica |
|---|---|---|---|---|---|---|
| 0 | 6.0800 | 8.8000 | 42.0000 | -3.9000 | 0.0300 | 8.4000 |
| 1 | 6.9500 | 5.7000 | 3.4000 | -3.7000 | 0.0320 | 6.2000 |
| 2 | 6.4000 | 4.6000 | 2.6000 | -3.9000 | 0.0120 | 9.0000 |
| 3 | 6.5000 | 3.3000 | 3.3000 | -3.9000 | 0.0340 | 6.3000 |
| 4 | 6.5600 | 3.9000 | 3.1000 | -3.8000 | 0.0150 | 6.6000 |
| 5 | 6.6400 | 9.0000 | 3.4000 | -3.3000 | 0.0240 | 6.5000 |
| 6 | 6.8800 | 11.8000 | 4.4000 | -2.8000 | 0.0200 | 6.6000 |
| 7 | 7.0200 | 6.6000 | 4.3000 | -2.9000 | 0.0330 | 5.8000 |
| 8 | 7.1100 | 11.5000 | 4.5000 | -2.6000 | 0.0460 | 6.1000 |
| 9 | 7.3300 | 12.9000 | 5.0000 | -2.2000 | 0.0890 | 7.4000 |
| 10 | 7.4400 | 15.2000 | 5.0000 | -2.1000 | 0.0190 | 6.8000 |
| 11 | 7.4100 | 12.5000 | 4.8000 | -2.1000 | 0.0130 | 7.2000 |
| 12 | 7.4500 | 16.6000 | 5.0000 | -2.0000 | 0.1600 | 7.6000 |
| 16 | 7.8000 | 15.0000 | 6.0000 | -1.5000 | 0.0280 | 8.0000 |
| 20 | 7.9700 | 17.0000 | 6.1000 | -1.4000 | 0.0210 | 8.1000 |
| 24 | 8.0200 | 17.0000 | 7.2000 | -1.3000 | 0.0410 | 8.4000 |
| 28 | 8.0900 | 17.0000 | 7.1000 | -1.3000 | 0.0230 | 8.7000 |
| 32 | 8.1700 | 18.0000 | 6.9000 | -1.2000 | 0.0530 | 5.8000 |
| 36 | 8.2600 | -4.0000 | -4.0000 | -4.0000 | -4.0000 | -4.0000 |
| 40 | 8.0200 | 21.0000 | 6.8000 | -1.3000 | 0.0270 | 9.0000 |
| 44 | 7.9400 | -4.0000 | -4.0000 | -4.0000 | -4.0000 | -4.0000 |
| 48 | 7.7700 | 21.0000 | 7.4000 | -1.6000 | 0.0300 | 10.0000 |

-6 or -10 means 'NOT DETECTED'
-4 means 'NOT ANALYZED'

## GENERAL MINERALS FOR PHASE IB

T2: Tolt Control

| Week | Iron | Magnesium | Chloride | Sulfate | Nitrate | TDS |
|---|---|---|---|---|---|---|
| 0 | 0.1200 | 1.4000 | 4.5000 | 2.0000 | 0.0700 | 18.0000 |
| 1 | 0.1200 | 0.5000 | 4.1000 | 0.9800 | -6.0000 | 19.0000 |
| 2 | 0.0600 | 0.7000 | 4.2000 | -6.0000 | 0.1000 | 23.0000 |
| 3 | 0.0360 | 0.5000 | 4.4000 | 4.8000 | -6.0000 | 41.0000 |
| 4 | -6.0000 | 0.5000 | 5.5000 | 3.5000 | -6.0000 | 35.0000 |
| 5 | 0.0600 | 0.6000 | 7.7000 | -6.0000 | 0.4000 | 31.0000 |
| 6 | 0.0500 | 0.4000 | 9.3000 | 2.6000 | 0.1000 | 28.0000 |
| 7 | 0.4300 | 0.4000 | 9.9000 | 1.9000 | 0.1000 | 30.0000 |
| 8 | 0.0980 | 0.6000 | 15.0000 | -6.0000 | 0.1000 | 32.0000 |
| 9 | 0.0230 | 0.5000 | 13.2000 | 2.1000 | 0.1000 | 54.0000 |
| 10 | 0.0690 | 0.4000 | 13.1000 | 2.1000 | 0.1000 | 37.0000 |
| 11 | 0.0610 | 0.2000 | 10.7000 | 1.9000 | 0.0900 | 39.0000 |
| 12 | 0.0730 | 0.4000 | 12.0000 | 1.9000 | 0.1000 | 43.0000 |
| 16 | 0.0590 | 0.5000 | 15.0000 | 2.6000 | 0.2000 | 60.0000 |
| 20 | 0.0600 | 0.3000 | 20.0000 | 3.0000 | 0.1000 | 62.0000 |
| 24 | 0.0800 | 0.2000 | 17.0000 | 2.6000 | 0.3000 | 64.0000 |
| 28 | 0.0700 | 0.3000 | 18.0000 | 2.7000 | 0.1000 | 68.0000 |
| 32 | 0.1700 | 0.2000 | 20.0000 | 2.3000 | 0.1000 | 67.0000 |
| 36 | -4.0000 | -4.0000 | -4.0000 | -4.0000 | -4.0000 | -4.0000 |
| 40 | 0.0420 | 0.3000 | 20.0000 | 3.3000 | -6.0000 | 68.0000 |
| 44 | -4.0000 | -4.0000 | -4.0000 | -4.0000 | -4.0000 | -4.0000 |
| 48 | 0.0300 | 0.2000 | 24.0000 | 2.6000 | 0.1000 | 71.0000 |

-6 or -10 means 'NOT DETECTED'
-4 means 'NOT ANALYZED'

GENERAL MINERALS FOR PHASE IB

T2: Tolt Control

| Week | Hardness (CaCO3) | Manganese | Fluoride | Free Chlorine | Temperature C | Dissolved Oxygen |
|---|---|---|---|---|---|---|
| 0 | 16.3000 | -6.0000 | 1.2000 | -4.0000 | 17.0000 | 11.2000 |
| 1 | 10.5000 | 0.1800 | 1.1000 | -4.0000 | 20.0000 | 9.6000 |
| 2 | 9.0000 | 0.0400 | 1.1000 | -6.0000 | 21.0000 | 8.4000 |
| 3 | 8.0000 | 0.0310 | 1.2000 | -6.0000 | 21.0000 | 7.3000 |
| 4 | 10.0000 | 0.0340 | 1.2000 | -6.0000 | 21.0000 | 5.9000 |
| 5 | 11.0000 | -6.0000 | 1.1000 | -6.0000 | 21.0000 | 5.8000 |
| 6 | 13.0000 | -6.0000 | 1.1000 | 0.4000 | 23.0000 | 5.4000 |
| 7 | 12.0000 | -6.0000 | 1.0000 | 1.2000 | 23.0000 | 5.0200 |
| 8 | 14.0000 | -6.0000 | 1.2000 | -6.0000 | 22.0000 | 5.4000 |
| 9 | 15.0000 | -6.0000 | 0.7000 | 0.4000 | 24.0000 | 4.9500 |
| 10 | 14.0000 | -6.0000 | 1.0000 | 1.3000 | 22.5000 | 5.4000 |
| 11 | 13.0000 | -6.0000 | 1.0000 | 1.4000 | 25.0000 | 5.4000 |
| 12 | 14.0000 | -6.0000 | 1.0000 | 0.5000 | 24.0000 | 5.9000 |
| 16 | 17.0000 | -6.0000 | 0.7000 | 0.6000 | 26.0000 | 6.8000 |
| 20 | 16.0000 | -6.0000 | 1.0000 | 0.9000 | 23.0000 | 7.3000 |
| 24 | 19.0000 | -6.0000 | 0.7000 | 0.9000 | 22.0000 | 6.4000 |
| 28 | 19.0000 | -6.0000 | 1.2000 | 0.5000 | 20.0000 | 6.9000 |
| 32 | 18.0000 | -6.0000 | 1.6000 | 1.1000 | 18.5000 | 8.5000 |
| 36 | -4.0000 | -4.0000 | -4.0000 | 0.6000 | 19.0000 | 8.4000 |
| 40 | 18.0000 | 0.0410 | 1.2000 | 1.0000 | 19.0000 | 9.4000 |
| 44 | -4.0000 | -4.0000 | -4.0000 | 1.0000 | 21.0000 | 9.7000 |
| 48 | 19.0000 | -6.0000 | 1.2000 | 0.8000 | 17.0000 | 10.1000 |

-6 or -10 means 'NOT DETECTED'
-4 means 'NOT ANALYZED'

## GENERAL MINERALS FOR PHASE IB

T3: Tolt, Seattle Corrosion Control (pH 8.0)

| Week | pH | Alkalinity | Calcium | Langelier Index | Zinc | Silica |
|---|---|---|---|---|---|---|
| 0 | 8.0200 | 12.4000 | 2.9000 | -2.0000 | 0.0400 | 6.0000 |
| 1 | 7.6400 | 14.3000 | 5.5000 | -1.7000 | 0.3800 | 5.9000 |
| 2 | 7.2600 | 17.0000 | 3.4000 | -1.7000 | 0.0090 | 8.0000 |
| 3 | 7.4700 | 17.4000 | 4.6000 | -1.5000 | 0.0220 | 5.9000 |
| 4 | 7.4600 | 18.7000 | 3.2000 | -1.6000 | 0.0200 | 6.0000 |
| 5 | 7.8000 | 20.3000 | 3.3000 | -1.6000 | 0.0590 | 5.9000 |
| 6 | 8.0700 | 24.3000 | 4.3000 | -1.3000 | 0.0280 | 6.2000 |
| 7 | 8.1000 | 21.8000 | 3.8000 | -1.4000 | 0.0390 | 5.6000 |
| 8 | 8.1200 | 22.1000 | 3.5000 | -1.5000 | 0.0420 | 5.0000 |
| 9 | 8.1500 | 23.1000 | 4.4000 | -1.3000 | 0.0460 | 6.4000 |
| 10 | 8.1000 | 23.6000 | 4.1000 | -1.4000 | 0.0340 | 6.2000 |
| 11 | 7.9600 | 23.6000 | 4.2000 | -1.3000 | 0.0310 | 6.3000 |
| 12 | 8.0100 | 28.6000 | 5.0000 | -1.2000 | 0.0530 | 6.5000 |
| 16 | 8.0200 | 24.0000 | 4.5000 | -1.3000 | 0.0310 | 6.8000 |
| 20 | 8.0300 | 26.0000 | 4.5000 | -1.3000 | 0.0280 | 6.8000 |
| 24 | 7.9100 | 28.0000 | 5.4000 | -1.2000 | 0.0350 | 6.6000 |
| 28 | 3.1500 | 26.0000 | 5.6000 | -1.3000 | 0.0530 | 7.0000 |
| 32 | 8.0600 | 25.0000 | 5.3000 | -1.4000 | 0.0400 | 6.0000 |
| 36 | 8.0100 | -4.0000 | -4.0000 | -4.0000 | -4.0000 | -4.0000 |
| 40 | 7.9900 | 29.0000 | 5.6000 | -1.3000 | 0.0350 | 7.5000 |
| 44 | 7.9000 | -4.0000 | -4.0000 | -4.0000 | -4.0000 | -4.0000 |
| 48 | 8.0500 | 29.0000 | 5.6000 | -1.3000 | 0.0340 | 8.0000 |

-6 or -10 means 'NOT DETECTED'
-4 means 'NOT ANALYZED'

GENERAL MINERALS FOR PHASE IB

| Week | Iron | Magnesium | Chloride | Sulfate | Nitrate | TDS |
|---|---|---|---|---|---|---|
| T3: Tolt. Seattle Corrosion Control (pH 8.0) | | | | | | |
| 0 | 0.1200 | 0.3000 | 5.5000 | 1.9000 | 0.0800 | 34.0000 |
| 1 | 0.1700 | 0.5000 | 5.8000 | 0.7500 | - 6.0000 | 35.0000 |
| 2 | 0.1100 | 0.7000 | 6.5000 | - 6.0000 | 0.2000 | 46.0000 |
| 3 | 0.0790 | 0.6000 | 6.3000 | 4.8000 | - 6.0000 | 65.0000 |
| 4 | 0.0590 | 0.4000 | 7.7000 | 3.2000 | - 6.0000 | 54.0000 |
| 5 | 0.1200 | 0.5000 | 10.2000 | - 6.0000 | 0.4000 | 48.0000 |
| 6 | 0.0800 | 0.5000 | 12.9000 | 2.3000 | 0.1000 | 64.0000 |
| 7 | 0.0590 | 0.5000 | 13.1000 | 2.1000 | 0.0900 | 51.0000 |
| 8 | 0.0990 | 0.4000 | 17.0000 | - 6.0000 | - 6.0000 | 37.0000 |
| 9 | 0.1500 | 0.4000 | 14.6000 | 2.0000 | 0.1000 | 76.0000 |
| 10 | 0.0820 | 0.4000 | 15.7000 | 2.2000 | 0.1000 | 47.0000 |
| 11 | 0.0510 | 0.2000 | 11.8000 | 1.8000 | 0.0600 | 54.0000 |
| 12 | 0.0580 | 0.5000 | 13.9000 | 1.9000 | 0.1000 | 68.0000 |
| 16 | 0.0640 | 0.5000 | 17.0000 | 2.5000 | 0.2000 | 75.0000 |
| 20 | 0.0600 | 0.3000 | 18.0000 | 4.0000 | 0.1000 | 71.0000 |
| 24 | 0.0800 | 0.3000 | 20.0000 | 1.8000 | - 6.0000 | 73.0000 |
| 28 | 0.3200 | 0.4000 | 21.0000 | 2.3000 | 0.1000 | 77.0000 |
| 32 | 0.2800 | 0.2000 | 22.0000 | 2.2000 | 0.1000 | 77.0000 |
| 36 | - 4.0000 | - 4.0000 | - 4.0000 | - 4.0000 | - 4.0000 | - 4.0000 |
| 40 | 0.0800 | 0.3000 | 23.0000 | 2.3000 | - 6.0000 | 78.0000 |
| 44 | - 4.0000 | - 4.0000 | - 4.0000 | - 4.0000 | - 4.0000 | - 4.0000 |
| 48 | 0.0450 | 0.2000 | 27.0000 | 2.5000 | 0.1000 | 79.0000 |

-6 or -10 means 'NOT DETECTED'
-4 means 'NOT ANALYZED'

## GENERAL MINERALS FOR PHASE IB

| Week | Hardness (CaCO3) | Manganese | Fluoride | Free Chlorine | Temperature C | Dissolved Oxygen |
|---|---|---|---|---|---|---|
| T3: Tolt, Seattle Corrosion Control (pH 8.0) | | | | | | |
| 0 | 8.4000 | 0.0200 | 1.2000 | -4.0000 | 17.0000 | 10.9000 |
| 1 | 10.8000 | 0.0200 | 1.1000 | -4.0000 | 20.0000 | 10.1000 |
| 2 | 11.0000 | 0.0400 | 1.0000 | -6.0000 | 21.0000 | 7.7500 |
| 3 | 14.0000 | 0.0300 | 1.2000 | -6.0000 | 21.0000 | 6.6000 |
| 4 | 10.0000 | 0.0390 | 1.2000 | 0.1000 | 21.0000 | 5.3000 |
| 5 | 10.0000 | -6.0000 | 1.1000 | -6.0000 | 21.0000 | 5.5000 |
| 6 | 13.0000 | -6.0000 | 1.2000 | -6.0000 | 23.0000 | 4.8500 |
| 7 | 12.0000 | -6.0000 | 1.1000 | 1.7000 | 23.0000 | 5.4500 |
| 8 | 10.0000 | 0.0170 | 1.1000 | 1.5000 | 22.0000 | 5.4500 |
| 9 | 13.0000 | -6.0000 | 0.8000 | 0.9000 | 24.0000 | 5.1000 |
| 10 | 12.0000 | -6.0000 | 1.2000 | 0.5000 | 22.5000 | 5.6000 |
| 11 | 11.0000 | -6.0000 | 1.0000 | 0.7000 | 25.0000 | 5.3000 |
| 12 | 15.0000 | -6.0000 | 1.0000 | -6.0000 | 24.0000 | 4.8000 |
| 16 | 13.0000 | -6.0000 | 1.1000 | 1.4000 | 26.0000 | 7.0000 |
| 20 | 12.0000 | -6.0000 | 1.0000 | 1.4000 | 23.0000 | 7.4000 |
| 24 | 15.0000 | -6.0000 | 1.3000 | 0.6000 | 22.0000 | 6.7000 |
| 28 | 16.0000 | -6.0000 | 1.0000 | 1.0000 | 20.0000 | 6.8000 |
| 32 | 14.0000 | 0.0310 | 1.5000 | 1.0000 | 18.5000 | 8.2000 |
| 36 | -4.0000 | -4.0000 | -4.0000 | 0.7000 | 19.0000 | 7.0000 |
| 40 | 15.0000 | 0.0400 | 1.2000 | 1.0000 | 19.0000 | 9.3000 |
| 44 | -4.0000 | -4.0000 | -4.0000 | 1.2000 | 21.0000 | 8.8000 |
| 48 | 15.0000 | -6.0000 | 1.9000 | 1.2000 | 17.0000 | 9.6000 |

-6 or -10 means 'NOT DETECTED'
-4 means 'NOT ANALYZED'

## GENERAL MINERALS FOR PHASE IB

| Week | pH | Alkalinity | Calcium | Langelier Index | Zinc | Silica |
|---|---|---|---|---|---|---|
| T4: Tolt, Seattle Corrosion Control (pH 9.0) | | | | | | |
| 0 | 9.0100 | 15.9000 | 3.6000 | -0.8000 | 0.0100 | 6.0000 |
| 1 | 8.7500 | 19.0000 | 4.0000 | -0.6000 | 0.0300 | 5.9000 |
| 2 | 8.6200 | 20.3000 | 4.0000 | -0.5000 | 0.0310 | 9.0000 |
| 3 | 8.8700 | 20.3000 | 3.8000 | -0.5000 | 0.0250 | 6.0000 |
| 4 | 8.9000 | 20.8000 | 3.8000 | -0.5000 | -6.0000 | 6.0000 |
| 5 | 8.9600 | 22.1000 | 3.8000 | -0.5000 | 0.0190 | 5.9000 |
| 6 | 8.8700 | 25.4000 | 4.9000 | -0.3000 | 0.0430 | 6.1000 |
| 7 | 8.9800 | 21.8000 | 4.2000 | -0.4000 | 0.0480 | 5.6000 |
| 8 | 8.9600 | 20.5000 | 3.9000 | -0.5000 | 0.0210 | 5.6000 |
| 9 | 8.9100 | 23.6000 | 4.8000 | -0.3000 | 0.0290 | 6.4000 |
| 10 | 8.9900 | 24.9000 | 4.6000 | -0.3000 | 0.0570 | 6.1000 |
| 11 | 8.9100 | 27.2000 | 4.7000 | -0.2000 | 0.0210 | 6.4000 |
| 12 | 8.9800 | 31.4000 | 4.8000 | -0.2000 | 0.0380 | 6.4000 |
| 16 | 9.0300 | 27.0000 | 4.8000 | -0.2000 | 0.0290 | 6.7000 |
| 20 | 8.9600 | 25.0000 | 4.8000 | -0.3000 | 0.0270 | 8.7000 |
| 24 | 8.9900 | 30.0000 | 5.7000 | -0.2000 | 0.0440 | 6.5000 |
| 28 | 9.0500 | 29.0000 | 5.7000 | -0.2000 | 0.0800 | 6.8000 |
| 32 | 9.0300 | 30.0000 | 5.4000 | -0.3000 | 0.0320 | 5.0000 |
| 36 | 8.9900 | -4.0000 | -4.0000 | -4.0000 | -4.0000 | -4.0000 |
| 40 | 8.8600 | 32.0000 | 5.5000 | -0.2000 | 0.0230 | 7.4000 |
| 44 | 8.8800 | -4.0000 | -4.0000 | -4.0000 | -4.0000 | -4.0000 |
| 48 | 9.0100 | 34.0000 | 5.6000 | -0.2000 | 0.0450 | 8.0000 |

-6 or -10 means 'NOT DETECTED'
-4 means 'NOT ANALYZED'

## GENERAL MINERALS FOR PHASE IB

T4: Tolt, Seattle Corrosion Control (pH 9.0)

| Week | Iron | Magnesium | Chloride | Sulfate | Nitrate | TDS |
|---|---|---|---|---|---|---|
| 0 | 0.0800 | 0.3000 | 7.7000 | 1.9000 | 0.0700 | 55.0000 |
| 1 | -6.0000 | 0.4000 | 6.7000 | 0.8200 | -6.0000 | 44.0000 |
| 2 | 0.1100 | 0.7000 | 6.7000 | -6.0000 | 0.2000 | 36.0000 |
| 3 | 0.0830 | 0.5000 | 8.0000 | 5.2000 | -6.0000 | 70.0000 |
| 4 | 0.0380 | 0.5000 | 9.2000 | 3.1000 | -6.0000 | 59.0000 |
| 5 | 0.0800 | 0.4000 | 11.8000 | -6.0000 | 0.6000 | 55.0000 |
| 6 | 0.0800 | 0.5000 | 12.1000 | 3.1000 | 0.2000 | 42.0000 |
| 7 | 0.0790 | 0.5000 | 12.3000 | 2.3000 | 0.1000 | 44.0000 |
| 8 | 0.0540 | 0.4000 | 17.0000 | -6.0000 | 0.1000 | 59.0000 |
| 9 | 0.0760 | 0.4000 | 14.2000 | 2.0000 | 0.1000 | 49.0000 |
| 10 | 0.0730 | 0.3000 | 15.6000 | 2.0000 | 0.1000 | 57.0000 |
| 11 | 0.0540 | 0.2000 | 13.5000 | 2.0000 | 0.1000 | 65.0000 |
| 12 | 0.0650 | 0.4000 | 13.7000 | 0.3000 | 0.1000 | 61.0000 |
| 16 | 0.0440 | 0.5000 | 18.0000 | 2.6000 | 0.2000 | 80.0000 |
| 20 | 0.0400 | 0.4000 | 20.0000 | 3.0000 | 0.2000 | 70.0000 |
| 24 | 0.1000 | 0.3000 | 18.0000 | 2.6000 | 0.1000 | 76.0000 |
| 28 | 0.3500 | 0.3000 | 21.0000 | 2.2000 | 0.2000 | 74.0000 |
| 32 | 0.1800 | 0.2000 | 20.0000 | 2.1000 | 0.1000 | 76.0000 |
| 36 | -4.0000 | -4.0000 | -4.0000 | -4.0000 | -4.0000 | -4.0000 |
| 40 | 0.0420 | 0.4000 | 20.0000 | 2.3000 | -6.0000 | 79.0000 |
| 44 | -4.0000 | -4.0000 | -4.0000 | -4.0000 | -4.0000 | -4.0000 |
| 48 | -6.0000 | 0.2000 | 24.0000 | 2.7000 | 0.2000 | 84.0000 |

-6 or -10 means 'NOT DETECTED'
-4 means 'NOT ANALYZED'

## GENERAL MINERALS FOR PHASE IB

T4: Tolt, Seattle Corrosion Control (pH 9.0)

| Week | Hardness (CaCO3) | Manganese | Fluoride | Free Chlorine | Temperature C | Dissolved Oxygen |
|---|---|---|---|---|---|---|
| 0 | 10.2000 | - 6.0000 | 1.2000 | - 4.0000 | 17.0000 | 10.8000 |
| 1 | 11.6000 | - 6.0000 | 1.1000 | - 4.0000 | 20.0000 | 9.4000 |
| 2 | 13.0000 | - 6.0000 | 1.1000 | - 6.0000 | 21.0000 | 9.0000 |
| 3 | 11.0000 | 0.0240 | 1.2000 | - 6.0000 | 21.0000 | 8.0000 |
| 4 | 12.0000 | 0.0510 | 1.2000 | - 6.0000 | 21.0000 | 8.5000 |
| 5 | 11.0000 | - 6.0000 | 1.1000 | - 6.0000 | 21.0000 | 8.2000 |
| 6 | 14.0000 | - 6.0000 | 1.2000 | 1.1000 | 23.0000 | 6.6000 |
| 7 | 13.0000 | 0.0150 | 1.2000 | 1.5000 | 23.0000 | 6.5000 |
| 8 | 11.0000 | - 6.0000 | 1.2000 | 1.0000 | 22.0000 | 6.8000 |
| 9 | 14.0000 | - 6.0000 | 0.8000 | 1.0000 | 24.0000 | 5.6000 |
| 10 | 13.0000 | - 6.0000 | 0.9000 | 0.4000 | 22.5000 | 5.9000 |
| 11 | 13.0000 | - 6.0000 | 1.1000 | 0.3000 | 25.0000 | 6.3000 |
| 12 | 14.0000 | - 6.0000 | 1.0000 | 0.4000 | 24.0000 | 6.4000 |
| 16 | 14.0000 | - 6.0000 | 1.1000 | 0.8000 | 26.0000 | 7.8000 |
| 20 | 14.0000 | - 6.0000 | 1.5000 | 1.5000 | 23.0000 | 7.2000 |
| 24 | 15.0000 | - 6.0000 | 1.3000 | 0.8000 | 22.0000 | 7.4000 |
| 28 | 15.0000 | - 6.0000 | 1.1000 | 0.6000 | 20.0000 | 6.5000 |
| 32 | 14.0000 | - 6.0000 | 1.4000 | 1.1000 | 18.5000 | 8.3000 |
| 36 | - 4.0000 | - 4.0000 | - 4.0000 | 1.1000 | 19.0000 | 7.3000 |
| 40 | 15.0000 | 0.0350 | 1.2000 | 0.9000 | 19.0000 | 8.8000 |
| 44 | - 4.0000 | - 4.0000 | - 4.0000 | 1.1000 | 21.0000 | 8.7000 |
| 48 | 15.0000 | - 6.0000 | 1.4000 | 1.1000 | 17.0000 | 9.6000 |

-6 or -10 means 'NOT DETECTED'
-4 means 'NOT ANALYZED'

## GENERAL MINERALS FOR PHASE IB

T5: Tolt, Seattle Corrosion
Control, 0.3 mg/l Zn. (pH 8.5)

| Week | pH | Alkalinity | Calcium | Langelier Index | Zinc | Silica |
|---|---|---|---|---|---|---|
| 0 | 8.4900 | 14.1000 | 3.0500 | -1.4000 | 0.2300 | 6.0000 |
| 1 | 7.7200 | 14.8000 | 3.4000 | -1.2000 | 0.3600 | 6.4000 |
| 2 | 7.4600 | 17.7000 | 3.1000 | -1.2000 | 0.2000 | 10.0000 |
| 3 | 7.9200 | 15.9000 | 2.9000 | -1.3000 | 0.2770 | 5.8000 |
| 4 | 8.0800 | 17.6000 | 3.0000 | -1.2000 | 0.2530 | 5.7000 |
| 5 | 8.2700 | 19.9000 | 3.0000 | -1.1000 | 0.2100 | 5.8000 |
| 6 | 8.4400 | 22.1000 | 4.2000 | -0.9000 | 0.2980 | 5.9000 |
| 7 | 8.6000 | 20.3000 | 3.4000 | -1.0000 | 0.2590 | 5.4000 |
| 8 | 8.6300 | 20.5000 | 3.1000 | -1.1000 | 0.2370 | 5.5000 |
| 9 | 8.5500 | 22.2000 | 3.9000 | -0.9000 | 0.2300 | 6.1000 |
| 10 | 2.4900 | 21.9000 | 3.8000 | -1.0000 | 0.2100 | 5.7000 |
| 11 | 8.4800 | 23.1000 | 3.7000 | -0.9000 | 0.2100 | 5.8000 |
| 12 | 8.4700 | 28.5000 | 3.8000 | -0.8000 | 0.2200 | 6.1000 |
| 16 | 8.6000 | 22.0000 | 3.8000 | -0.9000 | 0.2100 | 6.1000 |
| 20 | 8.4900 | 30.0000 | 3.8000 | -0.8000 | 0.1400 | 6.1000 |
| 24 | 3.4700 | 27.0000 | 4.6000 | -0.8000 | 0.1300 | 5.8000 |
| 28 | 8.4500 | 25.0000 | 4.6000 | -0.9000 | 0.1300 | 6.1000 |
| 32 | 8.5000 | 26.0000 | 4.7000 | -0.9000 | 0.1100 | 4.8000 |
| 36 | 8.4000 | -4.0000 | -4.0000 | -4.0000 | -4.0000 | -4.0000 |
| 40 | 3.3600 | 32.0000 | 4.5000 | -0.8000 | 0.1000 | 6.7000 |
| 44 | 8.3400 | -4.0000 | -4.0000 | -4.0000 | -4.0000 | -4.0000 |
| 48 | 8.5000 | 30.0000 | 4.7000 | -0.9000 | 0.1230 | 6.7000 |

-6 or -10 means 'NOT DETECTED'
-4 means 'NOT ANALYZED'

## GENERAL MINERALS FOR PHASE IB

| Week | Iron | Magnesium | Chloride | Sulfate | Nitrate | TDS |
|---|---|---|---|---|---|---|
| T5: Tolt, Seattle Corrosion Control, 0.3 mg/l Zn. (pH 8.5) | | | | | | |
| 0 | 0.0900 | 0.8000 | 5.6000 | 2.1000 | 0.0800 | 49.0000 |
| 1 | 0.0400 | 0.4000 | 4.8000 | 0.6000 | -6.0000 | 32.0000 |
| 2 | 0.1800 | 0.7000 | 5.4000 | -6.0000 | 0.1000 | 23.0000 |
| 3 | 0.0750 | 0.3000 | 6.3000 | 1.9000 | -6.0000 | 61.0000 |
| 4 | 0.0790 | 0.5000 | 7.3000 | 3.2000 | -6.0000 | 51.0000 |
| 5 | 0.0600 | 0.4000 | 10.3000 | -6.0000 | 0.4000 | 40.0000 |
| 6 | 0.0700 | 0.5000 | 10.3000 | 2.2000 | 0.1000 | 58.0000 |
| 7 | 0.0820 | 0.4000 | 11.8000 | 2.2000 | 0.1000 | 56.0000 |
| 8 | 0.0490 | 0.4000 | 15.7000 | -6.0000 | 0.1000 | 36.0000 |
| 9 | 0.0570 | 0.4000 | 13.5000 | 2.0000 | 0.1000 | 58.0000 |
| 10 | 0.0590 | 0.3000 | 15.6000 | 2.2000 | 0.2000 | 57.0000 |
| 11 | 0.0930 | 0.4000 | 12.7000 | 1.9000 | 0.1000 | 50.0000 |
| 12 | 0.0540 | 0.4000 | 14.3000 | 0.3000 | 0.1000 | 50.0000 |
| 16 | 0.0580 | 0.5000 | 18.0000 | 2.0000 | 0.1000 | 76.0000 |
| 20 | -6.0000 | 0.5000 | 15.0000 | 3.0000 | 0.1000 | 70.0000 |
| 24 | 0.0900 | 0.3000 | 20.0000 | 2.8000 | -6.0000 | 78.0000 |
| 28 | 0.0700 | 0.5000 | 25.0000 | 2.2000 | 0.1000 | 75.0000 |
| 32 | -6.0000 | 0.4000 | 23.0000 | 2.0000 | 0.1000 | 78.0000 |
| 36 | -4.0000 | -4.0000 | -4.0000 | -4.0000 | -4.0000 | -4.0000 |
| 40 | 0.0420 | 0.4000 | 25.0000 | 2.5000 | -6.0000 | 84.0000 |
| 44 | -4.0000 | -4.0000 | -4.0000 | -4.0000 | -4.0000 | -4.0000 |
| 48 | -6.0000 | 0.3000 | 29.0000 | 2.5000 | 0.2000 | 83.0000 |

-6 or -10 means 'NOT DETECTED'
-4 means 'NOT ANALYZED'

## GENERAL MINERALS FOR PHASE IB

T5: Tolt, Seattle Corrosion Control, 0.3 mg/l Zn, (pH 8.5)

| Week | Hardness (CaCO3) | Manganese | Fluoride | Free Chlorine | Temperature C | Dissolved Oxygen |
|---|---|---|---|---|---|---|
| 0 | 10.9000 | 0.0300 | 1.2000 | -4.0000 | 17.0000 | 10.5000 |
| 1 | 10.1000 | -6.0000 | 1.1000 | -4.0000 | 20.0000 | 10.0000 |
| 2 | 11.0000 | -6.0000 | 1.1000 | -6.0000 | 21.0000 | 8.6500 |
| 3 | 9.0000 | 0.0200 | 1.2000 | -6.0000 | 21.0000 | 7.8000 |
| 4 | 9.0000 | 0.0560 | 1.3000 | -6.0000 | 21.0000 | 7.6000 |
| 5 | 9.0000 | -6.0000 | 0.8000 | -6.0000 | 21.0000 | 7.4000 |
| 6 | 13.0000 | -6.0000 | 1.2000 | 1.1000 | 23.0000 | 6.2500 |
| 7 | 10.0000 | -6.0000 | 1.2000 | 0.7000 | 23.0000 | 6.9000 |
| 8 | 9.0000 | -6.0000 | 1.2000 | 1.0000 | 22.0000 | 6.2000 |
| 9 | 11.0000 | -6.0000 | 0.9000 | 0.7500 | 24.0000 | 6.4000 |
| 10 | 11.0000 | -6.0000 | 1.2000 | -6.0000 | 22.5000 | 6.7000 |
| 11 | 11.0000 | -6.0000 | 1.1000 | 0.9000 | 25.0000 | 6.1000 |
| 12 | 11.0000 | -6.0000 | 1.2000 | 0.2000 | 24.0000 | 6.4000 |
| 16 | 12.0000 | -6.0000 | 0.5000 | -6.0000 | 26.0000 | 7.9000 |
| 20 | 12.0000 | -6.0000 | 1.3000 | 1.3000 | 23.0000 | 7.0000 |
| 24 | 13.0000 | -6.0000 | 1.4000 | 0.9000 | 22.0000 | 7.0000 |
| 28 | 14.0000 | -6.0000 | 1.1000 | 0.9000 | 20.0000 | 6.3000 |
| 32 | 13.0000 | -6.0000 | 1.2000 | 1.2000 | 18.5000 | 7.9000 |
| 36 | -4.0000 | -4.0000 | -4.0000 | 0.8000 | 19.0000 | 7.4000 |
| 40 | 13.0000 | 0.0410 | 1.2000 | 1.1000 | 19.0000 | 9.1000 |
| 44 | -4.0000 | -4.0000 | -4.0000 | 1.3000 | 21.0000 | 8.7000 |
| 48 | 13.0000 | -6.0000 | 1.2000 | 1.3000 | 17.0000 | 9.8000 |

-6 or -10 means 'NOT DETECTED'
-4 means 'NOT ANALYZED'

# GENERAL MINERALS FOR PHASE IB

T6: Tolt, Seattle Corrosion Control, 0.6 mg/l Zn, (pH 8.0)

| Week | pH | Alkalinity | Calcium | Langelier Index | Zinc | Silica |
|---|---|---|---|---|---|---|
| 0 | 7.9900 | 12.8000 | 2.9000 | -1.9000 | 0.2300 | 6.0000 |
| 1 | 7.6300 | 14.1000 | 3.1000 | -1.8000 | 0.1970 | 5.8000 |
| 2 | 7.5400 | 15.6000 | 3.2000 | -1.7000 | 0.1800 | 8.0000 |
| 3 | 7.8100 | 12.6000 | 3.0000 | -1.8000 | 0.1300 | 5.7000 |
| 4 | 7.8400 | 13.9000 | 4.1000 | -1.7000 | 0.1440 | 5.7000 |
| 5 | 7.8800 | 15.9000 | 3.1000 | -1.7000 | 0.1750 | 5.8000 |
| 6 | 7.7800 | 19.5000 | 4.0000 | -1.5000 | 0.2120 | 5.9000 |
| 7 | 7.9800 | 16.8000 | 3.1000 | -1.7000 | 0.1210 | 5.5000 |
| 8 | 7.9600 | 16.1000 | 3.2000 | -1.7000 | 0.1200 | 5.8000 |
| 9 | 7.9900 | 17.8000 | 4.4000 | -1.4000 | 0.1300 | 6.1000 |
| 10 | 7.9700 | 17.8000 | 3.9000 | -1.5000 | 0.0870 | 5.5000 |
| 11 | 7.9600 | 18.8000 | 3.8000 | -1.5000 | 0.1000 | 5.8000 |
| 12 | 7.8000 | 23.1000 | 4.0000 | -1.4000 | 0.3900 | 6.0000 |
| 16 | 7.9600 | 22.0000 | 4.2000 | -1.3000 | 0.3700 | 6.9000 |
| 20 | 7.9600 | 21.0000 | 4.2000 | -1.4000 | 0.2500 | 6.2000 |
| 24 | 7.9100 | 25.0000 | 4.6000 | -1.3000 | 0.1960 | 5.9000 |
| 28 | 7.8900 | 21.0000 | 4.8000 | -1.4000 | 0.1830 | 6.1000 |
| 32 | 7.9700 | 23.0000 | 4.6000 | -1.5000 | 0.1300 | 4.7000 |
| 36 | 7.9500 | -4.0000 | -4.0000 | -4.0000 | -4.0000 | -4.0000 |
| 40 | 7.8800 | 26.0000 | 4.7000 | -1.4000 | 0.1200 | 6.5000 |
| 44 | 7.9300 | -4.0000 | -4.0000 | -4.0000 | -4.0000 | -4.0000 |
| 48 | 8.0600 | 26.0000 | 4.8000 | -1.4000 | 0.1260 | 6.7000 |

-6 or -10 means 'NOT DETECTED'
-4 means 'NOT ANALYZED'

## GENERAL MINERALS FOR PHASE IB

T6: Tolt, Seattle Corrosion Control, 0.6 mg/l Zn, (pH 8.0)

| Week | Iron | Magnesium | Chloride | Sulfate | Nitrate | TDS |
|---|---|---|---|---|---|---|
| 0 | 0.0900 | 0.9000 | 5.7000 | 2.0000 | 0.0800 | 29.0000 |
| 1 | 0.0600 | 0.4000 | 5.6000 | -6.0000 | -6.0000 | 46.0000 |
| 2 | 0.1100 | 0.7000 | 6.1000 | -6.0000 | 0.2000 | 25.0000 |
| 3 | 0.0750 | 0.4000 | 6.9000 | 5.7000 | -6.0000 | 65.0000 |
| 4 | 0.0530 | 0.5000 | 8.5000 | 3.3000 | -6.0000 | 55.0000 |
| 5 | 0.0900 | 0.4000 | 11.8000 | -6.0000 | 0.5000 | 38.0000 |
| 6 | 0.1000 | 0.5000 | 11.5000 | 2.2000 | 0.2000 | 42.0000 |
| 7 | 0.0450 | 0.4000 | 11.5000 | 2.1000 | 1.0000 | 47.0000 |
| 8 | 0.0880 | 0.4000 | 16.2000 | -6.0000 | 0.1000 | 35.0000 |
| 9 | 0.0610 | 0.5000 | 13.9000 | 2.0000 | 0.1000 | 44.0000 |
| 10 | 0.0500 | 0.4000 | 14.2000 | 4.7000 | 0.1000 | 54.0000 |
| 11 | 0.0480 | 0.3000 | 13.0000 | 1.9000 | 0.1200 | 48.0000 |
| 12 | 0.0480 | 0.4000 | 12.3000 | 1.7000 | 0.1000 | 50.0000 |
| 16 | 0.0600 | 0.4000 | 17.0000 | 2.7000 | 0.2000 | 74.0000 |
| 20 | -6.0000 | 0.4000 | 21.0000 | 2.0000 | 0.2000 | 68.0000 |
| 24 | 0.1000 | 0.4000 | 21.0000 | 4.9000 | -6.0000 | 75.0000 |
| 28 | 0.0700 | 0.5000 | 28.5000 | 2.3000 | 0.2000 | 75.0000 |
| 32 | -6.0000 | 0.4000 | 26.0000 | 2.3000 | 0.1000 | 79.0000 |
| 36 | -4.0000 | -4.0000 | -4.0000 | -4.0000 | -4.0000 | -4.0000 |
| 40 | 0.0520 | 0.4000 | 25.0000 | 2.7000 | -6.0000 | 79.0000 |
| 44 | -4.0000 | -4.0000 | -4.0000 | -4.0000 | -4.0000 | -4.0000 |
| 48 | -6.0000 | 0.4000 | 31.0000 | 2.3000 | 0.2000 | 84.0000 |

-6 or -10 means 'NOT DETECTED'
-4 means 'NOT ANALYZED'

## GENERAL MINERALS FOR PHASE IB

T6: Tolt, Seattle Corrosion
Control, 0.6 mg/l Zn, (pH 8.0)

| Week | Hardness (CaCO3) | Manganese | Fluoride | Free Chlorine | Temperature C | Dissolved Oxygen |
|---|---|---|---|---|---|---|
| 0 | 10.9000 | 0.0300 | 1.2000 | -4.0000 | 17.0000 | 10.7000 |
| 1 | 9.4000 | 0.0180 | 1.1000 | -4.0000 | 20.0000 | 9.8000 |
| 2 | 11.0000 | -6.0000 | 1.1000 | -6.0000 | 21.0000 | 8.3500 |
| 3 | 9.0000 | 0.0190 | 1.2000 | -6.0000 | 21.0000 | 7.8000 |
| 4 | 12.0000 | 0.0670 | 1.3000 | -6.0000 | 21.0000 | 8.3000 |
| 5 | 10.0000 | -6.0000 | 1.1000 | -6.0000 | 21.0000 | 8.3000 |
| 6 | 12.0000 | -6.0000 | 1.2000 | 1.3000 | 23.0000 | 6.9000 |
| 7 | 9.0000 | -6.0000 | 1.2000 | 1.4000 | 23.0000 | 7.1000 |
| 8 | 10.0000 | -6.0000 | 1.2000 | 0.4000 | 22.0000 | 6.7500 |
| 9 | 13.0000 | -6.0000 | 0.9000 | 0.9000 | 24.0000 | 5.5500 |
| 10 | 11.0000 | -6.0000 | 1.3000 | 0.4000 | 22.5000 | 6.8000 |
| 11 | 11.0000 | -6.0000 | 1.1000 | 0.5000 | 25.0000 | 5.4000 |
| 12 | 12.0000 | -6.0000 | 0.9000 | 0.5000 | 24.0000 | 6.5000 |
| 16 | 12.0000 | -6.0000 | 1.1000 | 0.4000 | 26.0000 | 7.8000 |
| 20 | 12.0000 | -6.0000 | 1.0000 | 1.0000 | 23.0000 | 7.3000 |
| 24 | 13.0000 | -6.0000 | 1.3000 | 0.5000 | 22.0000 | 7.8000 |
| 28 | 14.0000 | -6.0000 | 1.1000 | 0.4000 | 20.0000 | 6.9000 |
| 32 | 13.0000 | -6.0000 | 1.6000 | -6.0000 | 18.5000 | 11.1000 |
| 36 | -4.0000 | -4.0000 | -4.0000 | 1.5000 | 19.0000 | 7.6000 |
| 40 | 13.0000 | 0.0520 | 1.2000 | 1.0000 | 19.0000 | 9.4000 |
| 44 | -4.0000 | -4.0000 | -4.0000 | 1.1000 | 21.0000 | 9.1000 |
| 48 | 14.0000 | -6.0000 | 1.2000 | 1.0000 | 17.0000 | 9.7000 |

-6 or -10 means 'NOT DETECTED'
-4 means 'NOT ANALYZED'

GENERAL MINERALS FOR PHASE IB

T7: Tolt, Seattle Corrosion Control, Silicate (pH 8.0)

| Week | pH | Alkalinity | Calcium | Langelier Index | Zinc | Silica |
|---|---|---|---|---|---|---|
| 0 | 8.0200 | 13.5000 | 3.0000 | - 1.9000 | 0.0400 | 19.5000 |
| 1 | 7.8000 | 15.7000 | 3.4000 | - 1.7000 | 0.0190 | 19.6000 |
| 2 | - 4.0000 | 16.8000 | 4.1000 | - 1.6000 | 0.0450 | 15.0000 |
| 3 | 7.8200 | 16.2000 | 4.4000 | - 1.6000 | 0.0290 | 18.6000 |
| 4 | 7.8600 | 15.5000 | 3.7000 | - 1.7000 | 0.0230 | 18.2000 |
| 5 | 7.9400 | 18.1000 | 3.8000 | - 1.6000 | 0.0200 | 18.9000 |
| 6 | 7.8400 | 19.9000 | 5.2000 | - 1.4000 | 0.0410 | 18.3000 |
| 7 | 7.9500 | 19.2000 | 3.9000 | - 1.5000 | 0.0700 | 17.8000 |
| 8 | 8.0000 | 18.5000 | 4.0000 | - 1.5000 | 0.0500 | 16.9000 |
| 9 | 8.0000 | 19.6000 | 4.9000 | - 1.4000 | 0.0290 | 19.5000 |
| 10 | 7.9900 | 19.0000 | 4.7000 | - 1.4000 | 0.0530 | 18.0000 |
| 11 | 7.9900 | 21.7000 | 5.4000 | - 1.2000 | 0.0390 | 0.4000 |
| 12 | 8.0200 | 23.1000 | 4.8000 | - 1.3000 | 0.0160 | 20.4000 |
| 16 | 7.9800 | 35.0000 | 4.6000 | - 1.1000 | 0.0430 | 6.5000 |
| 20 | 7.9600 | 22.0000 | 4.7000 | - 1.4000 | 0.0230 | 2.0000 |
| 24 | 7.9100 | 23.0000 | 5.3000 | - 1.3000 | 0.0330 | 19.0000 |
| 28 | 7.9300 | 24.0000 | 5.5000 | - 1.3000 | 0.1050 | 19.0000 |
| 32 | 8.0500 | 24.0000 | 5.5000 | - 1.3000 | 0.0340 | 16.3000 |
| 36 | 8.0400 | - 4.0000 | - 4.0000 | - 4.0000 | - 4.0000 | - 4.0000 |
| 40 | 7.8600 | 26.0000 | 5.8000 | - 1.4000 | 0.0840 | 19.3000 |
| 44 | 7.9500 | - 4.0000 | - 4.0000 | - 4.0000 | - 4.0000 | - 4.0000 |
| 48 | 8.0900 | 26.0000 | 5.8000 | - 1.2000 | 0.0330 | 19.5000 |

-6 or -10 means 'NOT DETECTED'
-4 means 'NOT ANALYZED'

## GENERAL MINERALS FOR PHASE IB

| Week | Iron | Magnesium | Chloride | Sulfate | Nitrate | TDS |
|---|---|---|---|---|---|---|
| T7: Tolt, Seattle Corrosion Control, Silicate (pH 8.0) | | | | | | |
| 0 | 0.1400 | 0.8000 | 24.9000 | 2.0000 | 0.0700 | 85.0000 |
| 1 | 0.0600 | 0.4000 | 23.5000 | -6.0000 | -6.0000 | 91.0000 |
| 2 | 0.0900 | 0.7000 | 24.1000 | -6.0000 | 0.2000 | 95.0000 |
| 3 | 0.3890 | 0.4000 | 25.3000 | 6.0000 | -6.0000 | 114.0000 |
| 4 | 0.0640 | 0.4000 | 26.1000 | 3.4000 | -6.0000 | 77.0000 |
| 5 | 0.0900 | 0.5000 | 29.4000 | -6.0000 | 0.5000 | 82.0000 |
| 6 | 0.0900 | 0.5000 | 29.1000 | 2.7000 | 0.2000 | 93.0000 |
| 7 | 0.0630 | 0.4000 | 29.8000 | 2.0000 | 0.1300 | 86.0000 |
| 8 | 0.1790 | 0.4000 | 38.1000 | -6.0000 | 0.1000 | 72.0000 |
| 9 | 0.0870 | 0.4000 | 32.4000 | 1.9000 | 0.1000 | 76.0000 |
| 10 | 0.0840 | 0.4000 | 31.0000 | 2.2000 | 0.1000 | 93.0000 |
| 11 | 0.0650 | 0.3000 | 30.0000 | 3.9000 | 0.1000 | 88.0000 |
| 12 | 0.0600 | 0.4000 | 33.0000 | 1.8000 | 0.1000 | 88.0000 |
| 16 | -4.0000 | -4.0000 | -4.0000 | -4.0000 | -4.0000 | -4.0000 |
| 20 | 0.0600 | 0.4000 | 39.0000 | 3.0000 | 0.2000 | 100.0000 |
| 24 | 0.0900 | 0.3000 | 42.0000 | 1.7000 | -6.0000 | 113.0000 |
| 28 | 0.0800 | 0.5000 | 38.0000 | 2.7000 | 0.1000 | 100.0000 |
| 32 | -6.0000 | 0.4000 | 41.0000 | 2.2000 | 0.1000 | 110.0000 |
| 36 | -4.0000 | -4.0000 | -4.0000 | -4.0000 | -4.0000 | -4.0000 |
| 40 | 0.2800 | 0.4000 | 44.0000 | 2.0000 | -6.0000 | 112.0000 |
| 44 | -4.0000 | -4.0000 | -4.0000 | -4.0000 | -4.0000 | -4.0000 |
| 48 | 0.5200 | 0.3000 | 46.0000 | 2.2000 | 0.1000 | 112.0000 |

-6 or -10 means 'NOT DETECTED'
-4 means 'NOT ANALYZED'

## GENERAL MINERALS FOR PHASE IB

T7: Tolt, Seattle Corrosion Control, Silicate (pH 8.0)

| Week | Hardness (CaCO3) | Manganese | Fluoride | Free Chlorine | Temperature C | Dissolved Oxygen |
|---|---|---|---|---|---|---|
| 0 | 10.8000 | 0.0200 | 1.2000 | - 4.0000 | 17.0000 | 11.5000 |
| 1 | 10.1000 | 0.0150 | 1.1000 | - 4.0000 | 20.0000 | 9.9000 |
| 2 | 13.0000 | 0.0400 | 1.1000 | - 6.0000 | 21.0000 | 8.4500 |
| 3 | 13.0000 | 0.0270 | 1.3000 | - 6.0000 | 21.0000 | 8.2000 |
| 4 | 11.0000 | 0.0180 | 1.3000 | - 6.0000 | 21.0000 | 8.3000 |
| 5 | 11.0000 | - 6.0000 | 1.1000 | - 6.0000 | 21.0000 | 8.4000 |
| 6 | 15.0000 | - 6.0000 | 1.1000 | 1.5000 | 23.0000 | 6.7000 |
| 7 | 11.0000 | - 6.0000 | 1.1000 | 1.5000 | 23.0000 | 7.9500 |
| 8 | 12.0000 | - 6.0000 | 1.2000 | 0.9000 | 22.0000 | 7.2500 |
| 9 | 14.0000 | - 6.0000 | 0.9000 | 1.1000 | 24.0000 | 6.3000 |
| 10 | 13.0000 | - 6.0000 | 1.1000 | 0.8000 | 22.5000 | 7.6000 |
| 11 | 15.0000 | - 6.0000 | 1.0000 | 0.4000 | 25.0000 | 6.1000 |
| 12 | 14.0000 | - 6.0000 | 1.1000 | 0.8000 | 24.0000 | 6.9000 |
| 16 | - 4.0000 | - 4.0000 | - 4.0000 | - 6.0000 | 26.0000 | 7.9000 |
| 20 | 13.0000 | - 6.0000 | 1.4000 | 1.4000 | 23.0000 | 7.4000 |
| 24 | 14.0000 | - 6.0000 | 1.2000 | 0.9000 | 22.0000 | 7.9000 |
| 28 | 16.0000 | - 6.0000 | 1.1000 | 0.4000 | 20.0000 | 6.3500 |
| 32 | 15.0000 | - 6.0000 | 1.5000 | 0.8000 | 18.5000 | 8.9000 |
| 36 | - 4.0000 | - 4.0000 | - 4.0000 | 0.5000 | 19.0000 | 7.7000 |
| 40 | 16.0000 | 0.0340 | 1.3000 | 1.1000 | 19.0000 | 9.7000 |
| 44 | - 4.0000 | - 4.0000 | - 4.0000 | 0.9000 | 21.0000 | 9.3000 |
| 48 | 16.0000 | - 6.0000 | 1.2000 | 0.9000 | 17.0000 | 9.6000 |

-6 or -10 means 'NOT DETECTED'
-4 means 'NOT ANALYZED'

## GENERAL MINERALS FOR PHASE IB

TB: Tolt, Seattle Corrosion
Control, FeCl3 (0.2 mg/l-Fe)

| Week | pH | Alkalinity | Calcium | Langelier Index | Zinc | Silica |
|---|---|---|---|---|---|---|
| 0 | 8.0300 | 12.8000 | 3.2000 | - 1.9000 | 0.0300 | 6.0000 |
| 1 | 7.6300 | 14.3000 | 3.1000 | - 1.8000 | 0.0410 | 6.3000 |
| 2 | 7.4600 | 15.4000 | 3.3000 | - 1.7000 | 0.0410 | 7.0000 |
| 3 | 7.6600 | 15.4000 | 3.7000 | - 1.7000 | 0.0150 | 6.0000 |
| 4 | 7.7700 | 14.8000 | 5.0000 | - 1.5000 | 0.0090 | 5.9000 |
| 5 | 7.9500 | 14.1000 | 3.8000 | - 1.7000 | 0.0160 | 5.9000 |
| 6 | 7.9200 | 20.6000 | 4.6000 | - 1.4000 | 0.0240 | 6.2000 |
| 7 | 8.0000 | 17.9000 | 3.7000 | - 1.5000 | 0.0450 | 5.8000 |
| 8 | 8.1400 | 17.4000 | 3.4000 | - 1.6000 | 0.0370 | 5.6000 |
| 9 | 8.0900 | 19.0000 | 4.3000 | - 1.4000 | 0.0210 | 6.5000 |
| 10 | 8.0900 | 19.4000 | 3.3000 | - 1.6000 | 0.0220 | 6.0000 |
| 11 | 7.9700 | 20.6000 | 4.2000 | - 1.4000 | 0.0480 | 6.3000 |
| 12 | 8.0100 | 24.0000 | 4.2000 | - 1.3000 | 0.0530 | 6.5000 |
| 16 | 8.0100 | 23.0000 | 4.6000 | - 1.3000 | 0.0410 | 6.4000 |
| 20 | 8.0000 | 22.0000 | 4.8000 | - 1.3000 | 0.0270 | 6.9000 |
| 24 | 7.9200 | 25.0000 | 5.4000 | - 1.3000 | 0.0470 | 7.1000 |
| 28 | 7.9700 | 22.0000 | 7.1000 | - 1.2000 | 0.0390 | 6.9000 |
| 32 | 8.0400 | 24.0000 | 5.5000 | - 1.4000 | 0.0880 | 5.4000 |
| 36 | 7.9600 | - 4.0000 | - 4.0000 | - 4.0000 | - 4.0000 | - 4.0000 |
| 40 | 7.8800 | 26.0000 | 6.1000 | - 1.3000 | 0.0330 | 7.4000 |
| 44 | 7.8800 | - 4.0000 | - 4.0000 | - 4.0000 | - 4.0000 | - 4.0000 |
| 48 | 8.0300 | 28.0000 | 5.7000 | - 1.3000 | 0.0290 | 7.6000 |

-6 or -10 means 'NOT DETECTED'
-4 means 'NOT ANALYZED'

## GENERAL MINERALS FOR PHASE IB

TB: Tolt, Seattle Corrosion Control, FeCl3 (0.2 mg/l-Fe)

| Week | Iron | Magnesium | Chloride | Sulfate | Nitrate | TDS |
|---|---|---|---|---|---|---|
| 0 | 0.2800 | 0.8000 | 6.3000 | 2.0000 | 0.1400 | 40.0000 |
| 1 | 0.3400 | 0.3000 | 5.0000 | 0.5900 | -6.0000 | 33.0000 |
| 2 | 0.2800 | 0.7000 | 6.4000 | -6.0000 | 0.1000 | 39.0000 |
| 3 | 0.2720 | 0.4000 | 6.7000 | 1.6000 | -6.0000 | 62.0000 |
| 4 | 0.2480 | 0.6000 | 8.0000 | 3.4000 | -6.0000 | 57.0000 |
| 5 | 0.2600 | 0.4000 | 11.2000 | -6.0000 | 0.5000 | 48.0000 |
| 6 | 0.2900 | 0.5000 | 11.6000 | 2.4000 | 0.2000 | 51.0000 |
| 7 | 0.2400 | 0.4000 | 11.4000 | 2.3000 | -6.0000 | 52.0000 |
| 8 | 0.2260 | 0.4000 | 15.3000 | -6.0000 | 0.1000 | 32.0000 |
| 9 | 0.2600 | 0.4000 | 13.1000 | 2.0000 | 0.0100 | 42.0000 |
| 10 | 0.2500 | 0.4000 | 13.4000 | 2.4000 | -6.0000 | 46.0000 |
| 11 | 0.2500 | 0.4000 | 13.2000 | 2.0000 | 0.1100 | 48.0000 |
| 12 | 0.2500 | 0.4000 | 12.6000 | 1.8000 | 0.1000 | 48.0000 |
| 16 | 0.2300 | 0.4000 | 16.0000 | 1.9000 | 0.1000 | 71.0000 |
| 20 | 0.1700 | 0.4000 | 21.0000 | 3.0000 | 0.2000 | 70.0000 |
| 24 | 0.3300 | 0.3000 | 20.0000 | 1.4000 | -6.0000 | 78.0000 |
| 28 | 0.2100 | 0.9000 | 27.0000 | 2.6000 | 0.2000 | 73.0000 |
| 32 | 0.2600 | 0.4000 | 23.0000 | 2.3000 | 0.1000 | 74.0000 |
| 36 | -4.0000 | -4.0000 | -4.0000 | -4.0000 | -4.0000 | -4.0000 |
| 40 | 0.4900 | 0.3000 | 23.0000 | 2.3000 | -6.0000 | 79.0000 |
| 44 | -4.0000 | -4.0000 | -4.0000 | -4.0000 | -4.0000 | -4.0000 |
| 48 | 0.1900 | 0.3000 | 29.0000 | 2.6000 | 0.2000 | 80.0000 |

-6 or -10 means 'NOT DETECTED'
-4 means 'NOT ANALYZED'

## GENERAL MINERALS FOR PHASE IB

TB: Tolt, Seattle Corrosion
Control, FeCl3 (0.2 mg/l-Fe)

| Week | Hardness (CaCO3) | Manganese | Fluoride | Free Chlorine | Temperature C | Dissolved Oxygen |
|---|---|---|---|---|---|---|
| 0 | 11.3000 | 0.0200 | 1.2000 | -4.0000 | 17.0000 | 10.9000 |
| 1 | 9.0000 | 0.0090 | 1.2000 | -4.0000 | 20.0000 | 9.7000 |
| 2 | 11.0000 | -6.0000 | 1.1000 | -6.0000 | 21.0000 | 8.7000 |
| 3 | 11.0000 | 0.0220 | 1.3000 | -6.0000 | 21.0000 | 8.3000 |
| 4 | 15.0000 | 0.0170 | 1.3000 | -6.0000 | 21.0000 | 7.4000 |
| 5 | 11.0000 | -6.0000 | 1.1000 | -6.0000 | 21.0000 | 8.5000 |
| 6 | 14.0000 | -6.0000 | 1.1000 | 1.2000 | 23.0000 | 6.7000 |
| 7 | 11.0000 | -6.0000 | 1.1000 | 1.2000 | 23.0000 | 6.8500 |
| 8 | 10.0000 | -6.0000 | 1.2000 | 1.2000 | 22.0000 | 7.0000 |
| 9 | 12.0000 | -6.0000 | 0.9000 | 0.6500 | 24.0000 | 6.7000 |
| 10 | 10.0000 | -6.0000 | 1.1000 | -6.0000 | 22.5000 | 7.5000 |
| 11 | 12.0000 | -6.0000 | 1.0000 | 1.3000 | 25.0000 | 6.6000 |
| 12 | 12.0000 | -6.0000 | 1.0000 | 0.8000 | 24.0000 | 6.9000 |
| 16 | 13.0000 | 0.0120 | 0.9000 | -6.0000 | 26.0000 | 7.3000 |
| 20 | 14.0000 | -6.0000 | 1.1000 | 1.5000 | 23.0000 | 7.9000 |
| 24 | 15.0000 | -6.0000 | 1.3000 | 1.3000 | 22.0000 | 7.4000 |
| 28 | 21.0000 | -6.0000 | 1.1000 | 1.0000 | 20.0000 | 7.4000 |
| 32 | 15.0000 | -6.0000 | 1.5000 | 0.7000 | 18.5000 | 9.9000 |
| 36 | -4.0000 | -4.0000 | -4.0000 | 0.8000 | 19.0000 | 7.6000 |
| 40 | 17.0000 | 0.0340 | 1.3000 | 0.8000 | 19.0000 | 9.4000 |
| 44 | -4.0000 | -4.0000 | -4.0000 | 1.3000 | 21.0000 | 10.3000 |
| 48 | 15.0000 | -6.0000 | 1.2000 | 1.1000 | 17.0000 | 9.3000 |

-6 or -10 means 'NOT DETECTED'
-4 means 'NOT ANALYZED'

# APPENDIX C

## PHASE II DATA

### GENERAL MINERALS FOR PHASE II

Sampling Location: CH1

| Date | Sodium | Potassium | Calcium | Magnesium | Bicarbonate | Carbonate | Chloride | Sulfate | Nitrate | Fluoride | Hydroxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 23-Mar-1983 | -4.000 | -4.000 | 3.500 | 0.300 | 18.799 | 0.050 | 1.300 | 1.800 | -6.000 | 1.000 | -6.000 |
| 26-Apr-1983 | 4.000 | -6.000 | 3.400 | 0.300 | 9.800 | -6.000 | 1.500 | 1.800 | 0.100 | 0.500 | -6.000 |
| 24-May-1983 | 4.100 | -6.000 | 4.200 | 0.300 | 16.700 | 0.200 | 1.700 | 1.900 | 0.100 | 0.900 | -6.000 |
| 21-Jun-1983 | 4.000 | -4.000 | 4.200 | 0.300 | 17.000 | 0.020 | 1.100 | 1.600 | 0.200 | 0.500 | -6.000 |
| 22-Jul-1983 | 4.000 | -4.000 | 4.100 | 0.400 | 18.200 | 0.020 | 2.300 | 2.100 | 0.300 | 0.700 | -6.000 |
| 23-Aug-1983 | 4.300 | -4.000 | 4.500 | 0.300 | 18.200 | 0.040 | 0.900 | 2.100 | 0.100 | 0.500 | -6.000 |
| 21-Sep-1983 | 4.700 | -4.000 | 4.500 | 0.400 | 26.700 | 0.040 | 2.000 | 1.500 | 0.100 | 0.800 | -6.000 |
| 18-Oct-1983 | 4.700 | -4.000 | 4.900 | 0.400 | 13.200 | 0.060 | 2.500 | 2.300 | 0.040 | 1.400 | -6.000 |
| 19-Nov-1983 | 4.800 | -4.000 | 4.100 | 0.400 | 15.800 | 0.020 | 4.600 | 2.500 | 0.100 | 0.700 | -6.000 |
| 15-Dec-1983 | 4.400 | -4.000 | 7.800 | 0.500 | 21.900 | 0.030 | 2.600 | 2.500 | 0.200 | 1.100 | -6.000 |
| 21-Jan-1984 | 4.800 | -4.000 | 3.800 | 0.400 | 18.300 | 0.010 | 2.000 | 2.300 | 0.050 | 0.900 | -6.000 |
| 2-Mar-1984 | 4.600 | -4.000 | 3.600 | 0.400 | 22.000 | 0.010 | 1.400 | 1.600 | 0.100 | 1.000 | -6.000 |
| 2-Apr-1984 | 4.400 | -4.000 | 4.000 | 0.500 | 20.600 | 0.050 | 2.000 | 2.800 | 0.200 | 1.000 | 0.000 |

-6 or -10 means 'NOT DETECTED'
-4 means 'NOT ANALYZED'

## GENERAL MINERALS FOR PHASE II

Sampling Location: CH1

| Date | Conductivity | Alkalinity | TDS | Hardness | Iron | Manganese | Zinc | Silica | Field pH |
|---|---|---|---|---|---|---|---|---|---|
| 23-Mar-1983 | 42.000 | 13.000 | 20.000 | 10.000 | 0.130 | -6.000 | -6.000 | 5.400 | 7.850 |
| 26-Apr-1983 | 42.500 | 8.000 | 24.000 | 10.000 | 0.060 | -6.000 | 0.065 | 5.800 | 8.700 |
| 24-May-1983 | 47.000 | 14.000 | 31.000 | 12.000 | 0.064 | -6.000 | -6.000 | 7.000 | 8.800 |
| 21-Jun-1983 | 43.000 | 14.000 | 16.000 | 12.000 | 0.047 | -6.000 | -6.000 | 5.500 | 8.400 |
| 22-Jul-1983 | 48.000 | 15.000 | 33.000 | 12.000 | 0.069 | -6.000 | 0.009 | 5.000 | 7.900 |
| 23-Aug-1983 | 49.000 | 15.000 | 27.000 | 13.000 | 0.036 | -6.000 | -6.000 | 5.000 | 8.200 |
| 21-Sep-1983 | 48.000 | 22.000 | 31.000 | 13.000 | 0.120 | -4.000 | 0.011 | 5.400 | -4.000 |
| 18-Oct-1983 | 50.000 | 11.000 | 30.000 | 14.000 | 0.064 | -6.000 | -6.000 | 5.000 | 8.700 |
| 19-Nov-1983 | 50.000 | 13.000 | 28.000 | 12.000 | -6.000 | -6.000 | -6.000 | 5.700 | 8.200 |
| 15-Dec-1983 | 50.000 | 18.000 | 27.000 | 22.000 | 0.098 | -6.000 | -6.000 | 5.600 | 8.400 |
| 21-Jan-1984 | 50.000 | 15.000 | 20.000 | 11.000 | 0.120 | -6.000 | -6.000 | 6.000 | -4.000 |
| 2-Mar-1984 | 50.000 | 18.000 | 24.000 | 11.000 | 0.095 | -6.000 | -6.000 | 5.300 | -4.000 |
| 2-Apr-1984 | 50.000 | 17.000 | 20.000 | 12.000 | 0.079 | -6.000 | -6.000 | 5.700 | 8.100 |

-6 or -10 means 'NOT DETECTED'
-4 means 'NOT ANALYZED'

## GENERAL MINERALS FOR PHASE II

Sampling Location: CH1

| Date | Field Temp deg C | Field Langelier Index | DO | Cl Res. |
|---|---|---|---|---|
| 23-Mar-1983 | 8.500 | - 2.603 | 11.300 | - 6.000 |
| 26-Apr-1983 | 10.500 | - 2.368 | 11.000 | - 6.000 |
| 24-May-1983 | 12.000 | - 1.241 | - 4.000 | - 6.000 |
| 21-Jun-1983 | 13.000 | - 1.576 | - 4.000 | - 6.000 |
| 22-Jul-1983 | 15.000 | - 2.062 | - 4.000 | - 6.000 |
| 23-Aug-1983 | 17.000 | - 1.636 | - 4.000 | - 6.000 |
| 21-Sep-1983 | - 4.000 | - 10.000 | - 4.000 | - 4.000 |
| 18-Oct-1983 | 14.500 | - 1.550 | - 4.000 | - 6.000 |
| 19-Nov-1983 | 11.000 | - 1.980 | - 4.000 | 0.200 |
| 15-Dec-1983 | 9.000 | - 1.073 | - 4.000 | - 6.000 |
| 21-Jan-1984 | 4.000 | - 10.000 | - 4.000 | 0.200 |
| 2-Mar-1984 | 7.000 | - 10.000 | 13.200 | - 6.000 |
| 2-Apr-1984 | 8.500 | - 1.806 | 12.600 | - 6.000 |

-6 or -10 means 'NOT DETECTED'
-4 means 'NOT ANALYZED'

## GENERAL MINERALS FOR PHASE II

Sampling Location: CH1A

| Date | Sodium | Potassium | Calcium | Magnesium | Bicarbonate | Carbonate | Chloride | Sulfate | Nitrate | Fluoride | Hydroxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 26-Apr-1983 | 3.900 | - 6.000 | 3.500 | 0.400 | 13.400 | - 6.000 | 2.000 | 2.000 | 0.100 | 0.600 | - 6.000 |
| 24-May-1983 | 4.000 | - 6.000 | 4.700 | 0.300 | 16.900 | 0.080 | 2.400 | 2.100 | 0.100 | 0.400 | - 6.000 |
| 21-Jun-1983 | 4.300 | - 4.000 | 4.200 | 0.300 | 18.200 | 0.030 | 1.400 | 1.700 | 0.200 | 0.600 | - 6.000 |
| 22-Jul-1983 | 4.300 | - 4.000 | 4.100 | 0.300 | 15.800 | 0.010 | 2.300 | 1.900 | 0.100 | 0.700 | - 6.000 |
| 23-Aug-1983 | 3.900 | - 4.000 | 4.600 | 0.300 | 18.200 | 0.040 | 1.200 | 2.100 | 0.300 | 0.500 | - 6.000 |
| 21-Sep-1983 | 4.800 | - 4.000 | 4.600 | 0.400 | 26.799 | 0.020 | 2.700 | 1.600 | - 6.000 | 0.800 | - 6.000 |
| 18-Oct-1983 | 5.300 | - 4.000 | 6.500 | 0.500 | 19.500 | 0.020 | 3.400 | 2.100 | 0.080 | 1.400 | - 6.000 |
| 19-Nov-1983 | 4.700 | - 4.000 | 3.900 | 0.400 | 18.200 | 0.030 | 6.000 | 2.500 | 0.200 | 0.600 | - 6.000 |
| 15-Dec-1983 | 4.600 | - 4.000 | 5.000 | 0.400 | 21.900 | 0.040 | 3.400 | 2.600 | 0.100 | 1.100 | 0.000 |
| 21-Jan-1984 | 4.900 | - 4.000 | 3.700 | 0.400 | 18.299 | 0.010 | 3.000 | 2.300 | 0.800 | 0.900 | - 6.000 |
| 2-Mar-1984 | 4.800 | - 4.000 | 3.700 | 0.400 | 22.000 | - 6.000 | 2.100 | 2.200 | 0.100 | 1.000 | - 6.000 |
| 2-Apr-1984 | 4.200 | - 4.000 | 3.800 | 0.500 | 21.900 | 0.030 | 2.300 | 2.200 | 0.200 | 1.000 | - 6.000 |

-6 or -10 means 'NOT DETECTED'
-4 means 'NOT ANALYZED'

## GENERAL MINERALS FOR PHASE II

Sampling Location: CH1A

| Date | Conductivity | Alkalinity | TDS | Hardness | Iron | Manganese | Zinc | Silica | Field pH |
|---|---|---|---|---|---|---|---|---|---|
| 26-Apr-1983 | 44.000 | 11.000 | 28.000 | 10.000 | 0.055 | 0.017 | 0.610 | 5.600 | 8.600 |
| 24-May-1983 | 48.000 | 14.000 | 38.000 | 13.000 | 0.060 | -6.000 | 0.710 | 5.700 | 8.800 |
| 21-Jun-1983 | 46.000 | 15.000 | 21.000 | 12.000 | 0.081 | -6.000 | 0.630 | 5.300 | 8.300 |
| 22-Jul-1983 | 45.000 | 13.000 | 22.000 | 12.000 | 0.074 | -6.000 | 0.750 | 4.700 | 7.900 |
| 23-Aug-1983 | 53.000 | 15.000 | 25.000 | 13.000 | 0.110 | -6.000 | 0.740 | 5.200 | 8.200 |
| 21-Sep-1983 | 51.000 | 22.000 | 33.000 | 13.000 | 0.160 | -6.000 | 0.610 | 5.300 | -4.000 |
| 18-Oct-1983 | 58.000 | 16.000 | 35.000 | 18.000 | 0.120 | 0.014 | 0.700 | 5.000 | 8.700 |
| 19-Nov-1983 | 50.000 | 15.000 | 24.000 | 11.000 | -6.000 | -6.000 | 0.380 | 5.500 | 8.200 |
| 15-Dec-1983 | 60.000 | 18.000 | 29.000 | 14.000 | 0.240 | -6.000 | 0.580 | 5.600 | 8.400 |
| 21-Jan-1984 | 50.000 | 15.000 | 20.000 | 11.000 | 0.180 | 0.022 | 0.730 | 5.900 | -4.000 |
| 2-Mar-1984 | 50.000 | 18.000 | 24.000 | 11.000 | 0.200 | -6.000 | 0.790 | 5.400 | -4.000 |
| 2-Apr-1984 | 50.000 | 18.000 | 30.000 | 12.000 | 0.097 | -6.000 | 0.650 | 5.700 | 8.100 |

-6 or -10 means 'NOT DETECTED'
-4 means 'NOT ANALYZED'

## GENERAL MINERALS FOR PHASE II

Sampling Location: CH1A

| Date | Field Temp deg C | Field Langelier Index | DO | Cl Res. |
|---|---|---|---|---|
| 26-Apr-1983 | 10.500 | - 1.998 | 11.500 | - 6.000 |
| 24-May-1983 | 12.000 | - 1.150 | - 4.000 | - 6.000 |
| 21-Jun-1983 | 13.000 | - 1.623 | - 4.000 | - 6.000 |
| 22-Jul-1983 | 15.000 | - 2.286 | - 4.000 | - 6.000 |
| 23-Aug-1983 | 17.000 | - 1.612 | - 4.000 | - 6.000 |
| 21-Sep-1983 | - 4.000 | - 10.000 | - 4.000 | - 4.000 |
| 18-Oct-1983 | 14.500 | - 0.878 | - 4.000 | - 6.000 |
| 19-Nov-1983 | 11.000 | - 1.821 | - 4.000 | 0.200 |
| 15-Dec-1983 | 9.000 | - 1.329 | - 4.000 | - 6.000 |
| 21-Jan-1984 | 4.000 | - 10.000 | - 4.000 | 0.200 |
| 2-Mar-1984 | 7.000 | - 10.000 | 13.200 | - 6.000 |
| 2-Apr-1984 | 8.500 | - 1.823 | - 12.600 | - 6.000 |

-6 or -10 means 'NOT DETECTED'
-4 means 'NOT ANALYZED'

## GENERAL MINERALS FOR PHASE II

Sampling Location: CH2

| Date | Sodium | Potassium | Calcium | Magnesium | Bicarbonate | Carbonate | Chloride | Sulfate | Nitrate | Fluoride | Hydroxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 23-Mar-1983 | -4.000 | -4.000 | 4.100 | 0.300 | 19.100 | 0.030 | 0.800 | 1.900 | -6.000 | 1.000 | -6.000 |
| 26-Apr-1983 | 3.700 | -6.000 | 5.000 | 0.200 | 15.800 | 0.010 | 2.200 | 1.800 | 0.100 | 0.600 | -6.000 |
| 24-May-1983 | 3.800 | -6.000 | 5.500 | 0.200 | 16.900 | 0.060 | 2.500 | 1.900 | 0.100 | 0.600 | -6.000 |
| 21-Jun-1983 | 4.300 | -4.000 | 4.900 | 0.300 | 18.200 | 0.030 | 1.400 | 1.700 | 0.200 | 0.600 | -6.000 |
| 22-Jul-1983 | 4.300 | -4.000 | 5.000 | 0.200 | 19.400 | 0.040 | 3.400 | 2.000 | 0.400 | 0.700 | -6.000 |
| 23-Aug-1983 | 3.500 | -4.000 | 5.300 | 0.200 | 19.400 | 0.050 | 1.300 | 1.900 | 0.100 | 0.500 | -6.000 |
| 21-Sep-1983 | 5.100 | -4.000 | 6.500 | 0.300 | 28.200 | 0.400 | 2.600 | 1.500 | -6.000 | 0.800 | -6.000 |
| 18-Oct-1983 | 5.100 | -4.000 | 5.900 | 0.400 | 13.300 | 0.030 | 3.300 | 2.400 | 0.200 | 1.500 | -6.000 |
| 19-Nov-1983 | 4.500 | -4.000 | 6.800 | 0.100 | 21.900 | 0.020 | 6.500 | 2.500 | 0.700 | 0.800 | -6.000 |
| 15-Dec-1983 | 3.900 | -4.000 | 5.500 | -6.000 | 22.000 | 0.010 | 3.400 | 2.400 | -6.000 | 1.100 | -6.000 |
| 21-Jan-1984 | 9.400 | 0.300 | 5.400 | 0.200 | 19.100 | 0.200 | 13.000 | 3.800 | 0.050 | 1.000 | -6.000 |
| 2-Mar-1984 | 4.700 | -4.000 | 5.200 | 0.200 | -4.000 | -6.000 | 2.000 | 1.800 | -4.000 | 1.000 | 0.000 |
| 2-Apr-1984 | 4.500 | -4.000 | 5.400 | 0.300 | 22.900 | 0.600 | 2.400 | 2.200 | 0.200 | 1.000 | 0.170 |

-6 or -10 means 'NOT DETECTED'
-4 means 'NOT ANALYZED'

## GENERAL MINERALS FOR PHASE II

Sampling Location: CH2

| Date | Conductivity | Alkalinity | TDS | Hardness | Iron | Manganese | Zinc | Silica | Field pH |
|---|---|---|---|---|---|---|---|---|---|
| 23-Mar-1983 | 41.500 | 14.000 | 20.000 | 12.000 | 0.280 | 0.016 | -6.000 | 5.300 | 8.400 |
| 26-Apr-1983 | 50.000 | 13.000 | 30.000 | 13.000 | 0.067 | -6.000 | 0.370 | 5.600 | 9.100 |
| 24-May-1983 | 49.000 | 14.000 | 30.000 | 15.000 | 0.068 | -6.000 | 0.540 | 5.800 | 8.800 |
| 21-Jun-1983 | 47.000 | 15.000 | 18.000 | 14.000 | 0.072 | -6.000 | 0.340 | 5.300 | 8.500 |
| 22-Jul-1983 | 52.000 | 16.000 | 26.000 | 13.000 | 0.057 | -6.000 | 0.400 | 5.000 | 8.300 |
| 23-Aug-1983 | 52.999 | 16.000 | 25.000 | 14.000 | 0.050 | 0.069 | 0.430 | 4.900 | 8.100 |
| 21-Sep-1983 | 56.000 | 24.000 | 37.000 | 18.000 | 0.084 | -6.000 | 0.270 | 5.200 | -4.000 |
| 18-Oct-1983 | 53.999 | 11.000 | 35.000 | 16.000 | 0.076 | -6.000 | 0.300 | 4.900 | 8.890 |
| 19-Nov-1983 | 60.000 | 18.000 | 36.000 | 17.000 | -6.000 | -6.000 | 0.061 | 5.800 | 9.300 |
| 15-Dec-1983 | 55.000 | 18.000 | 28.000 | 14.000 | 0.084 | -6.000 | 0.240 | 5.300 | 9.000 |
| 21-Jan-1984 | 80.000 | 16.000 | 46.000 | 14.000 | 0.110 | -6.000 | 0.250 | 5.500 | -4.000 |
| 2-Mar-1984 | -4.000 | -4.000 | 44.000 | 14.000 | 0.099 | -6.000 | 0.250 | 4.900 | -4.000 |
| 2-Apr-1984 | 50.000 | 20.000 | 30.000 | 15.000 | 0.045 | -6.000 | 0.380 | 5.700 | 8.800 |

-6 or -10 means 'NOT DETECTED'
-4 means 'NOT ANALYZED'

## GENERAL MINERALS FOR PHASE II

| Date | Field Temp deg C | Field Langelier Index | DO | Cl Res. |
|---|---|---|---|---|
| Sampling Location: CH2 | | | | |
| 23-Mar-1983 | 12.000 | - 1.625 | 11.400 | - 6.000 |
| 26-Apr-1983 | 14.000 | - 0.830 | 10.600 | - 6.000 |
| 24-May-1983 | 17.000 | - 0.944 | - 4.000 | - 6.000 |
| 21-Jun-1983 | 17.000 | - 1.242 | - 4.000 | - 6.000 |
| 22-Jul-1983 | 19.000 | - 1.370 | - 4.000 | - 6.000 |
| 23-Aug-1983 | 20.500 | - 1.508 | - 4.000 | - 6.000 |
| 21-Sep-1983 | - 4.000 | - 10.000 | - 4.000 | - 4.000 |
| 18-Oct-1983 | 15.000 | - 1.090 | - 4.000 | - 6.000 |
| 19-Nov-1983 | 12.000 | - 0.218 | - 4.000 | - 6.000 |
| 15-Dec-1983 | 8.500 | - 0.677 | - 4.000 | - 6.000 |
| 21-Jan-1984 | 6.000 | - 10.000 | - 4.000 | - 6.000 |
| 2-Mar-1984 | 9.000 | - 10.000 | 12.000 | - 6.000 |
| 2-Apr-1984 | 11.500 | - 0.785 | 12.200 | - 6.000 |

-6 or -10 means 'NOT DETECTED'
-4 means 'NOT ANALYZED'

## GENERAL MINERALS FOR PHASE II

Sampling Location: D3

| Date | Sodium | Potassium | Calcium | Magnesium | Bicarbonate | Carbonate | Chloride | Sulfate | Nitrate | Fluoride | Hydroxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 26-Apr-1983 | 4.900 | - 6.000 | 3.000 | 0.400 | 14.600 | - 6.000 | 1.500 | 2.000 | 0.100 | 0.500 | - 6.000 |
| 24-May-1983 | 3.600 | - 6.000 | 3.600 | 0.400 | 13.200 | 0.080 | 1.400 | 1.900 | 0.100 | 0.800 | - 6.000 |
| 21-Jun-1983 | 4.300 | - 4.000 | 4.100 | 0.300 | 18.200 | 0.040 | 1.000 | 1.700 | 0.200 | 0.500 | - 6.000 |
| 22-Jul-1983 | 4.300 | - 4.000 | 4.000 | 0.300 | 15.800 | 0.020 | 2.400 | 2.300 | 0.300 | 0.900 | - 6.000 |
| 23-Aug-1983 | 4.800 | - 4.000 | 3.900 | 0.400 | 17.000 | 0.040 | 0.900 | 2.100 | 0.100 | 0.500 | - 6.000 |
| 21-Sep-1983 | 4.800 | - 4.000 | 4.200 | 0.400 | 21.799 | 0.070 | 2.100 | 1.500 | 0.100 | 0.800 | - 6.000 |
| 18-Oct-1983 | 4.900 | - 4.000 | 4.700 | 0.600 | 10.900 | 0.030 | 2.400 | 2.300 | 0.090 | 1.400 | - 6.000 |
| 19-Nov-1983 | 4.700 | - 4.000 | 3.100 | 0.200 | 13.400 | 0.020 | 4.500 | 2.300 | 0.800 | 0.900 | - 6.000 |
| 15-Dec-1983 | 4.800 | - 4.000 | 5.200 | 0.400 | 17.400 | 0.300 | 2.800 | 2.900 | 0.050 | 1.200 | - 6.000 |
| 21-Jan-1984 | 15.500 | 0.500 | 3.900 | 1.700 | 29.100 | 0.080 | 20.000 | 6.000 | 0.050 | 0.900 | - 6.000 |
| 28-Feb-1984 | 4.600 | - 4.000 | 3.400 | 0.500 | 22.000 | 0.010 | 1.500 | 1.700 | 0.100 | 1.000 | - 6.000 |
| 2-Apr-1984 | 4.400 | - 4.000 | 3.400 | 0.500 | 18.200 | 0.040 | 1.700 | 2.200 | 0.200 | 1.000 | - 6.000 |

-6 or -10 means 'NOT DETECTED'
-4 means 'NOT ANALYZED'

## GENERAL MINERALS FOR PHASE II

Sampling location: D3

| Date | Conductivity | Alkalinity | TDS | Hardness | Iron | Manganese | Zinc | Silica | Field pH |
|---|---|---|---|---|---|---|---|---|---|
| 26-Apr-1983 | 42.000 | 12.000 | 26.000 | 6.000 | 0.032 | - 6.000 | 0.023 | 5.600 | 8.700 |
| 24-May-1983 | 39.000 | 11.000 | 30.000 | 11.000 | 0.064 | - 6.000 | 0.009 | 5.800 | 7.900 |
| 21-Jun-1983 | 43.000 | 15.000 | 17.000 | 12.000 | 0.081 | - 6.000 | - 6.000 | 5.100 | 8.400 |
| 22-Jul-1983 | 44.000 | 13.000 | 24.000 | 11.000 | 0.095 | - 6.000 | 0.018 | 5.000 | 8.000 |
| 23-Aug-1983 | 49.000 | 14.000 | 24.000 | 11.000 | 0.068 | - 6.000 | - 6.000 | 4.900 | 7.600 |
| 21-Sep-1983 | 47.000 | 18.000 | 25.000 | 12.000 | 0.130 | 0.016 | - 6.000 | 5.300 | - 4.000 |
| 18-Oct-1983 | 46.000 | 9.000 | 30.000 | 14.000 | 0.079 | 0.020 | 0.007 | 5.000 | 8.280 |
| 19-Nov-1983 | 50.000 | 11.000 | 27.000 | 9.000 | 0.044 | - 6.000 | - 6.000 | 5.600 | 8.300 |
| 15-Dec-1983 | 50.000 | 15.000 | 27.000 | 15.000 | 0.160 | - 6.000 | - 6.000 | 5.900 | 8.300 |
| 21-Jan-1984 | 120.000 | 24.000 | 66.000 | 17.000 | 0.140 | - 6.000 | 0.018 | 5.800 | - 4.000 |
| 28-Feb-1984 | 50.000 | 18.000 | 20.000 | 11.000 | 0.100 | - 6.000 | - 6.000 | 5.200 | 8.900 |
| 2-Apr-1984 | 50.000 | 15.000 | 28.000 | 11.000 | 0.059 | - 6.000 | - 6.000 | 5.500 | 8.400 |

-6 or -10 means 'NOT DETECTED'
-4 means 'NOT ANALYZED'

## GENERAL MINERALS FOR PHASE II

| Date | Field Temp deg C | Field Langelier Index | DO | Cl Res. |
|---|---|---|---|---|
| Sampling Location: D3 | | | | |
| 26-Apr-1983 | 9.000 | - 1.988 | 11.700 | 0.500 |
| 24-May-1983 | 11.000 | - 2.668 | - 4.000 | 0.040 |
| 21-Jun-1983 | 12.000 | - 1.541 | - 4.000 | 0.400 |
| 22-Jul-1983 | 14.000 | - 2.270 | - 4.000 | 0.500 |
| 23-Aug-1983 | 15.500 | - 2.492 | - 4.000 | 0.600 |
| 21-Sep-1983 | - 4.000 | - 10.000 | - 4.000 | - 4.000 |
| 18-Oct-1983 | 13.000 | - 2.190 | - 4.000 | 0.700 |
| 19-Nov-1983 | 9.000 | - 2.456 | - 4.000 | 0.800 |
| 15-Dec-1983 | 5.500 | - 1.570 | - 4.000 | 0.100 |
| 21-Jan-1984 | - 4.000 | - 10.000 | - 4.000 | 0.500 |
| 28-Feb-1984 | 5.000 | - 1.126 | 12.000 | 0.500 |
| 2-Apr-1984 | 7.000 | - 1.816 | 12.600 | 0.600 |

-6 or -10 means 'NOT DETECTED'
-4 means 'NOT ANALYZED'

## GENERAL MINERALS FOR PHASE II

| Date | Sodium | Potassium | Calcium | Magnesium | Bicarbonate | Carbonate | Chloride | Sulfate | Nitrate | Fluoride | Hydroxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Sampling Location: D4 | | | | | | | | | | | |
| 26-Apr-1983 | 3.800 | - 6.000 | 4.700 | 2.000 | 17.000 | 0.020 | 1.200 | 2.000 | 0.200 | 0.700 | - 6.000 |
| 24-May-1983 | 5.500 | - 6.000 | 4.300 | 0.200 | 17.799 | 0.200 | 1.500 | 2.100 | 0.100 | 0.600 | - 6.000 |
| 21-Jun-1983 | 4.200 | - 4.000 | 5.600 | 0.100 | 17.200 | 1.300 | 1.000 | 1.700 | 0.200 | 0.600 | 0.340 |
| 22-Jul-1983 | 4.200 | - 4.000 | 5.500 | 0.100 | 19.200 | 0.100 | 2.500 | 2.000 | 0.200 | 0.700 | - 6.000 |
| 23-Aug-1983 | 3.800 | - 4.000 | 5.400 | 0.200 | 19.000 | 0.200 | 0.900 | 2.100 | 0.200 | 0.500 | - 6.000 |
| 21-Sep-1983 | 5.400 | - 4.000 | 6.800 | 0.300 | 24.400 | 1.000 | 2.000 | 1.600 | - 6.000 | 0.800 | 0.170 |
| 18-Oct-1983 | 4.200 | - 4.000 | 5.100 | 0.200 | 16.800 | 0.500 | 2.700 | 2.400 | 0.200 | 1.400 | 0.170 |
| 19-Nov-1983 | 4.700 | - 4.000 | 4.800 | 0.100 | 15.600 | 0.100 | 4.500 | 2.400 | 0.600 | 0.800 | - 6.000 |
| 15-Dec-1983 | 4.000 | - 4.000 | 3.600 | 0.400 | 13.300 | 0.040 | 2.600 | 2.500 | 0.050 | 1.200 | - 6.000 |
| 21-Jan-1984 | 4.800 | - 4.000 | 4.600 | 0.200 | 18.700 | 0.300 | 2.000 | 2.200 | 0.700 | 0.900 | - 6.000 |
| 28-Feb-1984 | 4.600 | - 4.000 | 4.500 | 0.300 | 19.500 | 0.010 | 2.000 | 2.000 | 0.300 | 1.100 | - 6.000 |
| 2-Apr-1984 | 4.300 | - 4.000 | 4.500 | 0.300 | 27.000 | 0.400 | 1.800 | 2.400 | 0.200 | 1.000 | - 6.000 |

-6 or -10 means 'NOT DETECTED'
-4 means 'NOT ANALYZED'

## GENERAL MINERALS FOR PHASE II

| Date | Conductivity | Alkalinity | TDS | Hardness | Iron | Manganese | Zinc | Silica | Field pH |
|---|---|---|---|---|---|---|---|---|---|
| Sampling Location: D4 | | | | | | | | | |
| 26-Apr-1983 | 46.000 | 14.000 | 24.000 | 13.000 | 0.110 | -6.000 | 0.047 | 6.000 | 9.300 |
| 24-May-1983 | 49.000 | 15.000 | 33.000 | 12.000 | 0.074 | -6.000 | -6.000 | 6.200 | 9.100 |
| 21-Jun-1983 | 50.000 | 17.000 | 18.000 | 14.000 | 0.068 | -6.000 | -6.000 | 5.600 | 9.100 |
| 22-Jul-1983 | 51.000 | 16.000 | 25.000 | 14.000 | 0.101 | 0.021 | -6.000 | 5.200 | 8.900 |
| 23-Aug-1983 | 52.000 | 16.000 | 36.000 | 14.000 | 0.056 | -6.000 | -6.000 | 5.300 | -4.000 |
| 21-Sep-1983 | 56.000 | 22.000 | 39.000 | 18.000 | 0.120 | 0.017 | -6.000 | 6.000 | -4.000 |
| 18-Oct-1983 | 50.000 | 15.000 | 30.000 | 14.000 | 0.120 | 0.018 | -6.000 | 5.300 | 9.070 |
| 19-Nov-1983 | 60.000 | 13.000 | 36.000 | 12.000 | -6.000 | -6.000 | -6.000 | 5.700 | 9.200 |
| 15-Dec-1983 | 50.000 | 11.000 | 25.000 | 11.000 | 0.280 | -6.000 | -6.000 | 5.700 | 9.000 |
| 21-Jan-1984 | 50.000 | 16.000 | 24.000 | 12.000 | 0.091 | -6.000 | -6.000 | 5.800 | 8.900 |
| 28-Feb-1984 | 50.000 | 16.000 | 26.000 | 13.000 | 0.110 | -6.000 | -6.000 | 5.500 | 8.700 |
| 2-Apr-1984 | 50.000 | 23.000 | 20.000 | 13.000 | 0.044 | -6.000 | -6.000 | 5.800 | 9.500 |

-6 or -10 means 'NOT DETECTED'
-4 means 'NOT ANALYZED'

## GENERAL MINERALS FOR PHASE II

Sampling Location: D4

| Date | Field Temp deg C | Field Langelier Index | DO | Cl Res. |
|---|---|---|---|---|
| 26-Apr-1983 | 12.500 | - 0.607 | 11.000 | |
| 24-May-1983 | 15.000 | - 0.815 | - 4.000 | - 6.000 |
| 21-Jun-1983 | 16.000 | - 0.477 | - 4.000 | - 6.000 |
| 22-Jul-1983 | 17.500 | - 0.724 | - 4.000 | - 6.000 |
| 23-Aug-1983 | 19.000 | - 10.000 | - 4.000 | - 6.000 |
| 21-Sep-1983 | - 4.000 | - 10.000 | - 4.000 | 0.100 |
| 18-Oct-1983 | 14.000 | - 0.711 | - 4.000 | - 4.000 |
| 19-Nov-1983 | 11.000 | - 0.814 | - 4.000 | 0.400 |
| 15-Dec-1983 | 8.000 | - 1.602 | - 4.000 | 0.400 |
| 21-Jan-1984 | 6.000 | - 0.994 | - 4.000 | - 6.000 |
| 28-Feb-1984 | 7.500 | - 1.195 | - 4.000 | - 6.000 |
| 2-Apr-1984 | 9.500 | - 0.118 | 11.800 | 0.100 |
| | | | 13.100 | 0.200 |

-6 or -10 means 'NOT DETECTED'
-4 means 'NOT ANALYZED'

| Date | Zinc mg/l |
|---|---|
| Sampling Location: | S1 |
| 28-Apr-1983 | 0.2700 |
| 24-Mar-1983 | 0.0560 |
| 19-Dec-1983 | 0.2400 |
| 25-May-1983 | 0.4600 |
| 22-Jun-1983 | 0.3500 |
| 2-Mar-1984 | 0.8900 |
| 25-Jul-1983 | 0.1900 |
| 25-Aug-1983 | 0.3500 |
| 2-Apr-1984 | 0.3600 |
| 22-Sep-1983 | 0.3100 |
| 21-Jan-1984 | 0.2700 |
| 19-Oct-1983 | 0.2300 |
| Sampling Location: | S2 |
| 21-Jan-1984 | 0.6900 |
| 2-Mar-1984 | 0.5300 |
| 2-Apr-1984 | 0.3800 |
| 19-Oct-1983 | 0.5100 |
| 23-Nov-1983 | 0.7100 |
| 19-Dec-1983 | 0.4100 |
| 24-Mar-1983 | 0.0800 |
| 28-Apr-1983 | 0.1500 |
| 25-Aug-1983 | 0.3200 |
| 22-Sep-1983 | 0.4000 |
| 22-Jun-1983 | 0.3200 |
| 25-Jul-1983 | 0.4000 |
| 25-May-1983 | 0.8100 |

| Date | Total Zinc mg/l | Soluble Zinc mg/l |
|---|---|---|
| Sampling Location: | CH3 | |
| 24-Mar-1983 | 0.0150 | - 6.0000 |
| 22-Jun-1983 | 0.5100 | 0.4800 |
| 22-Sep-1983 | 0.4700 | 0.4500 |
| 19-Dec-1983 | 0.5100 | 0.4200 |
| 2-Apr-1984 | 0.9800 | 0.7700 |
| Sampling Location: | CH4 | |
| 24-Mar-1983 | 0.0210 | 0.0080 |
| 22-Jun-1983 | 0.7800 | 0.3300 |
| 22-Sep-1983 | 1.4000 | 0.4500 |
| 19-Dec-1983 | 1.3000 | 0.0710 |
| 2-Apr-1984 | 0.3300 | 0.1200 |

-6 means 'NOT DETECTED'

# ASBESTOS FOR PHASE II

| Date | Chrysotile MFL |
|---|---|
| Sampling location: D3 | |
| 26-Apr-1983 | 2.9000 |
| 24-May-1983 | 2.1000 |
| 21-Jun-1983 | 0.4000 |
| 22-Jul-1983 | 1.1000 |
| 23-Aug-1983 | 0.7000 |
| 21-Sep-1983 | 0.5000 |
| 18-Oct-1983 | 0.9000 |
| 19-Nov-1983 | 3.7000 |
| 15-Dec-1983 | 6.6000 |
| 21-Jan-1984 | 16.0000 |
| 2-Mar-1984 | 20.0000 |
| 2-Apr-1984 | 5.1000 |
| Sampling location: D4 | |
| 26-Apr-1983 | 140.0000 |
| 24-May-1983 | 13.0000 |
| 21-Jun-1983 | 9.9000 |
| 22-Jul-1983 | 8.9000 |
| 23-Aug-1983 | 4.8000 |
| 21-Sep-1983 | 7.2000 |
| 18-Oct-1983 | 2.7000 |
| 19-Nov-1983 | 5.7000 |
| 15-Dec-1983 | 3.0000 |
| 21-Jan-1984 | 16.0000 |
| 2-Mar-1984 | 23.0000 |
| 2-Apr-1984 | 4.8000 |

# ASBESTOS FOR PHASE II

| Date | Chrysotile MFL |
|---|---|
| Sampling location: CH1 | |
| 23-Mar-1983 | 16.0000 |
| 26-Apr-1983 | 3.0000 |
| 24-May-1983 | 6.3000 |
| 21-Jun-1983 | 3.4000 |
| 22-Jul-1983 | 1.3000 |
| 23-Aug-1983 | 1.0000 |
| 22-Sep-1983 | 1.1000 |
| 19-Oct-1983 | 1.8000 |
| 19-Nov-1983 | 4.7000 |
| 15-Dec-1983 | 2.7000 |
| 21-Jan-1984 | 17.0000 |
| 2-Mar-1984 | 23.0000 |
| 2-Apr-1984 | 9.9000 |
| Sampling location: CH1A | |
| 26-Apr-1983 | 6.7000 |
| 24-May-1983 | 5.5000 |
| 21-Jun-1983 | 2.1000 |
| 22-Jul-1983 | 1.8000 |
| 23-Aug-1983 | 0.3000 |
| 21-Sep-1983 | 3.9000 |
| 19-Oct-1983 | 2.5000 |
| 19-Nov-1983 | 2.8000 |
| 15-Dec-1983 | 2.3000 |
| 21-Jan-1984 | 15.0000 |
| 2-Mar-1984 | 20.0000 |
| 2-Apr-1984 | 6.0000 |

# ASBESTOS FOR PHASE II

| Date | Chrysotile MFL |
|---|---|
| Sampling location: CH2 | |
| 23-Mar-1983 | 39.0000 |
| 26-Apr-1983 | 45.0000 |
| 24-May-1983 | 25.0000 |
| 21-Jun-1983 | 6.6000 |
| 22-Jul-1983 | 5.6000 |
| 23-Aug-1983 | 2.2000 |
| 21-Sep-1983 | 5.2000 |
| 18-Oct-1983 | 3.2000 |
| 19-Nov-1983 | 170.0000 |
| 15-Dec-1983 | 4.9000 |
| 21-Jan-1984 | 20.0000 |
| 2-Mar-1984 | 31.0000 |
| 2-Apr-1984 | 130.0000 |